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INVESTIGATIONS OF AN ELECTRICAL GLOW DISCHARGE,
WHEN INSERTED IN SUPERSONIC AIRFLOW,
TO DETERMINE ITS DEPENDENCE ON PRESSURE AND VELOCITY

by

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July 28, 1949

A Thesis Submitted to the Faculty of
the Graduate School in Partial
Fulfillment of the Requirements for
the Degree of
Master of Science

7/12/57
5/2/57

Investigation of an electrical circuit diagram.
The diagram is of a circuit diagram.
to determine the conditions of operation and voltage.

at 1000 hours in the morning

Department of Agriculture, Washington

Director, of Agriculture
Washington, D. C.

July 12, 1957

A copy is submitted to the Bureau of
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100	Indexing of Wind, Pressure and Vacuum

SUMMARY

It has been found in this preliminary investigation that an electrical glow discharge from a sharp point, when inserted in supersonic airflow ($M = 1.0$ to $M = 3.0$) is sensitive to the following conditions.

1. The glow current is definitely pressure sensitive at supersonic velocities.
2. Any Mach number change from $M = 1$ to $M = 3$ effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and a positive wire polarity.
4. Platinum wire of 0.003-inch minimum diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough flow discharge for this experiment ($M = 1.0$ to $M = 3.0$).
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

It has been found in this preliminary investigation that as electrical glow discharges from a sharp point, when initiated in a vacuum at $p = 1.0$ in $H = 5.0$, is sensitive to the following conditions.

1. The glow current is relatively constant regardless of electrode separation.
2. Any sharp corner between $p = 1$ to $p = 5$ allows the glow current.
3. A greater voltage is required to initiate a glow current for larger electrode spacing, a larger wire size, and a positive wire polarity.
4. Filament wire of 0.003-inch diameter diameter could be used in this investigation because any smaller wire size would mean it was initiated in a vacuum at $p = 1.0$.
5. Current flow is to be 50 milliamperes gives enough flow discharge for this experiment ($p = 1.0$ to $p = 5.0$).
6. The shape of the glass and the material from which it is made affect the current flow.
7. The glow changes in size with changes in gas pressure.
8. The glow changes in size with changes in electric field.
9. This device might be used as a static pressure measuring instrument and possibly as a flow meter.

INTRODUCTION

Frank David Werner¹⁾ in his investigation of the possible utilization of an electrical glow discharge as a means for measuring airflow characteristics, found that the glow current from a sharp point is markedly pressure sensitive, somewhat dependent upon velocity, slightly dependent upon humidity, and apparently not dependent upon ordinary temperatures. His investigation was made through a velocity range from zero to 400 feet per second or a Mach number range of from zero to about 0.4.

The primary endeavor in the writer's investigation was to make a preliminary exploration to determine if such a glow would function at all in supersonic airflow, to design apparatus with which an electrical glow discharge from a sharp point could be studied, and also to determine if the glow is pressure or velocity dependent at Mach numbers greater than one. The Mach number range used in this investigation was from 1.0 to 3.0. The facility in which this investigation was carried out was constructed by the writer and Lt. Cdr. F. X. Timmes (graduate student) at the University of Minnesota Aeronautical Laboratories at the Rosemount Research Center, Rosemount, Minnesota.

Since this is the first time an electrical glow discharge from a sharp point has been inserted in supersonic airflow to investigate its dependence on pressures and Mach numbers, it is to be expected that the results obtained will have some experimental errors because of inadequate instrumentation and should be used only as a

guide for later and more elaborate studies. Experience in designing and using equipment to make this investigation should lead to the development of more accurate instrumentation, and to the elimination of some of these errors. However, the general trend of dependence upon Mach number and pressure of the electrical glow discharge from a sharp point will be shown in this investigation.

For this study it was decided to construct a special small size wind tunnel instead of using any of the University's full-scale tunnels. The reason for this decision was the necessity for more flexibility during investigations even though the accuracy of ultimate results may be lowered. Since this was the first use of the sharp point glow discharge in supersonic airflow, many adaptations were more convenient in this setup than in the full-scale tunnel. It is logical that the ultimate check of the data obtained in this tunnel would have to be made in a full-scale tunnel, but that step is beyond the scope of this paper. A single step attempt to use the needle in a full-scale tunnel is shown in the appendix.

The writer is grateful to Professor John D. Akerman for his advice and general direction of the research. Mr. Frank D. Werner was very helpful in the actual design of all the electrical equipment. Professor J. W. Braithwaite was of great assistance in the design and construction of the supersonic wind tunnel.

gains for later and more extensive studies. Improvements
 in designing and using equipment to make this investigation
 should lead to the development of more accurate instrument-
 ation, and to the elimination of some of these errors.
 However, the present trend of cooperation with these workers
 and presence of the electrical give message from a
 sharp point will be shown in this investigation.
 For this study it was decided to consider a
 special case also with some interest of other work in
 the University's laboratory. The reason for this
 decision was the necessity for more limited study
 investigations over the range of values of
 units may be observed. Since this was the first use of
 the sharp point and design in previous studies,
 many experiments were more concerned in this study than
 in the laboratory. It is hoped that the study
 which of the data obtained in this study would show to
 be made in a laboratory, but that was in 1920.
 The hope of this paper is that it will be of use
 to the study in a laboratory which is shown in the
 appendix.

The writer is grateful to Professor John D.
 Adams for his advice and general direction of the
 research. Mr. John D. Adams was very helpful in the
 design of all the electrical equipment. (Appendix)
 A. H. Robinson was of great assistance in the design
 and construction of the apparatus and instrument.

METHODS

The Laval nozzle was made of lucite for two reasons: First, because of its transparency, through lucite it is possible to observe the electrical glow discharge at different Mach numbers and at different static pressures. Second, since lucite is a good insulator, there was no danger of a current flow to ground through the nozzle if a short occurred. Lucite has proved to be an excellent material to satisfy the above requirements.

The probes were designed to be strong enough so that they would not bend in supersonic airflow. Also, a coating of arcylold, which is a liquid plastic that hardens in about 48 hours, was used on each probe not only to give more rigidity but also to act as an insulator. The insulatory properties of the coating were essential, especially where the probes were close together, to avoid arcing downstream of the platinum wire. Care was taken not to coat the plate circuit nor the platinum wire with the liquid plastic. Arcylold proved to be an excellent insulator.

When the plate circuit was positive and the wire negative, measurable current readings were recorded. When the wire was positive and the plate negative, current readings were so small that the electronic equipment designed for these tests did not detect any current flow. Since measurable current readings were recorded when the wire was negative, this type of circuit was used to obtain

The first series was made of single test
reactions. First, because of its frequency, through
which it is possible to observe the electrical wave
change at different load numbers and at different static
pressures. Second, since there is a good knowledge
there was no change of a constant flow in current through
the series in a short circuit. Since the first is in
an electrical circuit it is really the same phenomenon.
The series was designed to be strong enough
so that they would not break in subsequent series. Also,
a coating of graphite, which is a little plastic in
nature in water in water, was used on each test set
only to give more rigidity and also to put on an insulator.
The insulating properties of the series were essential,
especially where the series were also tested. It
avoid strong connections at the highest side. One was
taken not to break the glass circuit and the highest side
with the liquid circuit. Graphite proved to be an
excellent insulator.
When the series circuit was tested and the
also tested, necessarily current readings were recorded.
When the first was tested and the first negative, current
readings were so small that the electrical equipment
was used for those tests and not before any current flow.
These readings current readings were recorded when the
also was negative. This type of circuit was used in series

the electrical glow discharge current readings. The theory behind this phenomenon is explained extensively in the paper written by Frank David Werner¹).

The writer has found in this investigation that current readings were obtained up to 350 microamperes at high voltage settings. At these high voltages and currents the electrical glow discharge was almost at an arcing stage; therefore, erratic current readings resulted at this high voltage. For this reason, lower current readings were used in the magnitude of from 60 to 80 microamperes. Enough points were recorded at these lower currents to plot smooth curves as are shown in Figures 2 through 6. From this it can be concluded that the use of lower current will give more stable readings and will give more accurately the trend of events under investigation.

The electronic equipment was designed to give from zero to 10,000 volts positive and from zero to 10,000 volts negative. These two circuits could then be connected in a series to give a range of from zero to 20,000 volts. It was not necessary to use more than 10,000 volts; therefore, it was not necessary to connect the two circuits together. The positive voltage supply was used throughout the entire investigation. The positive lead was connected to the plate circuit which also acted as the static probe while the ground (shield

The electrical and discharge system consists of the theory behind this phenomenon is explained separately in the paper entitled "The Discharge System".

The water has been in this investigation

that various readings were obtained up to 300 millimeters at high voltage readings. At these high voltages and currents the electrical field discharge was almost at an ending stage; therefore, various current readings were obtained at this high voltage. For this reason, lower current readings were used in the magnitude of from 50 to 100 millimeters. These points were recorded at these lower currents to give a more correct picture of the current in figure 2 through 4. From this it can be concluded that the use of lower current will give more stable readings and all five were recorded; the trend of events under investigation.

The electronic equipment was obtained in five from zero to 10,000 volts positive and from zero to 10,000 volts negative. These two electric fields were connected in a series to give a range of from zero to 20,000 volts. It was not necessary to use zero and 10,000 volts; therefore, it was not necessary to connect the two electric fields. The positive voltage supply was used throughout the entire investigation. The positive lead was connected to the plate directly while the negative lead was connected to the ground (which

of co-ax cable) of the circuit was connected to the probe holding the 0.003-inch platinum wire.

at once revised; all the circles was composed in the

series ending the 0.000-inch distance after

it was found that a single line would be

produced by the same line of circles.

The circles were then drawn on a single line of circles.

It was found that the circles were drawn on a single line of circles.

The circles were then drawn on a single line of circles.

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The circles were then drawn on a single line of circles.

EQUIPMENT

Figure 31 shows the wind tunnel nozzle, the manometer board, the electrical equipment, and the probes. Figure 25 is a drawing, to scale, of the wind tunnel. Figure 26 is a scale drawing of the Laval nozzle blocks. Figures 27, 28, and 29 are diagrams of the electrical equipment.

The wind tunnel was supplied with a continuous flow of dry air from a 225-pound-per-square-inch storage tank of 1750 cubic foot capacity. The high pressure air leaves the tank through a 1-inch high pressure steel pipe. A 1-inch gate valve was used to control the air leaving the high pressure storage tank. The air enters the stagnation chamber of the wind tunnel through a 2-inch pipe. A 2-inch globe valve was installed in the 2-inch pipe line for use as a throttling valve. Stagnation pressures in the stagnation chamber were maintained by adjusting the 2-inch throttling valve.

A total head pressure gage was designed as shown in Figure 25. It consisted of a 1/4-inch steel pipe which held a hypodermic needle. This pipe was placed in the stagnation chamber as shown in the scale drawing of the wind tunnel (Figure 25). One end of this steel tube was plugged while the other end was connected to a pressure gage with a scale from zero to 100 pounds per square inch. It was found that this gage gave pressure readings accurate to within one percent of their correct value.

Figure 27, 28, and 29 are diagrams of the electrical equipment.

The wind tunnel was supplied with a continuous flow of dry air from a 200-pound-per-square-inch storage tank of 150 cubic foot capacity. The high pressure air leaves the tank through a 1-inch high pressure orifice. A 1-inch side drive was used to operate the air leaving the high pressure storage tank. The air enters the expansion chamber at the inlet through a 2-inch pipe. A 2-inch side drive was installed in the 2-inch pipe line for use as a throttling valve. Measurement pressure in the expansion chamber were obtained by substituting the 2-inch throttling valve.

A total hand pressure gauge was indicated as shown in Figure 28. It consisted of a 1 1/2-inch steel pipe which held a hypodermic needle. This pipe was placed in the vibration chamber as shown in the section drawing at the right (Figure 29). One end of this pipe was plugged while the other end was connected to a pressure gauge with a scale from zero to 100 pounds per square inch. It was found that this gave very reliable readings because it within one percent of liquid column.

A standard type mercury manometer was constructed and used throughout this investigation to measure static pressure. Figure 31 shows this manometer as it was used to measure static pressures.

Figure 25 shows the bell-mouth entrance to the nozzle. This bell-mouth, made of hydrostone, proved to be very satisfactory. No cracking or chipping of the bell-mouth was noticed at the completion of this investigation.

Figure 26 is a scale drawing of the Laval nozzle blocks. The blocks and side plates were made of lucite and were designed to give a Mach number from 1.0 to 3.0, but a manufacturing error was made which gave a slightly different Mach number. This difference is shown in Figure 1. It can also be seen in Figure 1 that the experimental Mach numbers are slightly less than the theoretical Mach numbers at the same positions in the nozzle, but still gave satisfactory Mach numbers for $M = 1.0$ to $M = 3.1$.

The probes, as shown in Figures 30 and 33, were made of 1/4-inch steel tubing. The static probe also acted as the plate of the circuit. A 1/16-inch brass tube was inserted in the upstream end of the static probe. A static hole was drilled in this brass tube 8 diameters from the upstream end. The upstream end of the 1/16-inch brass tube was closed by silver solder and ground to a very fine point. A 1/16-inch solid steel rod was inserted in the upstream end of the glow probe that held the

A standard type mercury manometer was connected to the end of the tube. This investigation is made at a pressure of 10 mm. Hg. The results are shown in Figure 1. The results are shown in Figure 1.

Figure 1 shows the relationship between the pressure and the rate of flow. The results are shown in Figure 1. The results are shown in Figure 1.

Figure 2 is a graph showing the relationship between the pressure and the rate of flow. The results are shown in Figure 2. The results are shown in Figure 2.

The results are shown in Figure 3. The results are shown in Figure 3. The results are shown in Figure 3.

platinum wire. This upstream end of the solid steel rod was also ground to a very fine point. The 0.003-inch platinum wire was soldered to the upstream sharp end of the steel rod.

Both probes were coated with arcyloid which is a liquid plastic that hardens in about 48 hours. These probes were mounted in lucite holders that were fastened to the probe support. The probe support could be moved back and forth on a steel track, thus enabling the probes to be set at any position desired in the nozzle. Figure 32 shows the probe support and the track on which it could be moved.

The electronic equipment was designed in two separate parts. The circuit for part one is shown in Figure 28. This circuit produced a negative voltage of from zero to 10,000 volts. The circuit for part two is shown in Figure 29. This second circuit produced a positive voltage of from zero to 10,000 volts. Voltmeter and ammeter circuits (Direct Current) were designed as shown and were used to measure currents in microamperes and voltages. All voltmeter and ammeter readings are accurate to within 5 percent of their actual value. Both circuits were installed in the same panel as shown in Figure 31.

platinum wire. This specimen was of the same size and was also ground to a very fine point. The 0.002-inch platinum wire was adjusted to the specimen about one of the steel rods.

Both probes were coated with a special which is a light plastic sheet between in about an hour. These probes were mounted in inside holders that were fastened to the probe support. The probe support could be moved back and forth on a steel track, thus enabling the probes to be set at any position desired in the specimen. Figure 22 shows the probe support and the track on which it could be moved.

The electronic equipment was designed in two separate parts. The circuit for part one is shown in Figure 23. This circuit produced a negative voltage of from zero to 10,000 volts. The circuit for part two is shown in Figure 24. This second circuit produced a positive voltage of from zero to 10,000 volts. Voltages and current densities (Electron Density) were designed as shown and were used to measure currents in microamperes and voltages. All voltages and current readings are accurate to within 10 percent of their actual values. Both circuits were included in the same panel as shown in Figure 25.

TEST PROCEDURE

The static probe, which also acted as the plate circuit of the electrical glow discharge, was inserted in the nozzle at 0.71-inch from the throat with the static hole just opposite the 0.71-inch position. At this position in the nozzle runs were made for different Mach numbers. The stagnation pressure was changed through a range of values to determine the stagnation pressure that produced the approximate theoretical Mach number in the nozzle at the 0.71-inch position. At positions of 1-inch, 2, 3, and 4 inches downstream the same procedure as described above was followed. A curve of the results is shown in Figure 1.

It was found that stagnation pressures of 25, 30, and 40 pounds per square inch gage gave a Mach number of 2.08 at the 1-inch position. Stagnation pressures of 40, 50, and 60 pounds per square inch gage gave a Mach number of 2.44 at the 2-inch position. The 3 and 4-inch positions were probed in the same manner, and Mach numbers of 2.8 and 3.1 were established. Stagnation pressures of 70, 80, and 90 pounds per square inch gage were used at the 3-inch position, and 90, 94, and 100 pounds per square inch were used at the 4-inch position. It was found that below certain stagnation pressures the Mach number at any position could not be obtained. Since the nozzle did not have a diffuser attached to its exit, these high stagnation pressures are to be expected and check very

THE RESULTS

The static force, which also acted as the force
 itself of the electrical force distribution, was inserted
 in the matrix at 0.75-inch level and forced with the static
 force just opposite the 0.75-inch position. At this
 position in the matrix were made for different force
 members. The elongation pressure was changed through a
 range of values to determine the elongation pressure that
 produced the approximate theoretical maximum stress in the
 matrix at the 0.75-inch position. At position of 1-inch,
 2, 3, and 4 inches respectively the same procedure was fol-
 lowed above was followed. A series of the results is
 shown in figure 1.

It was found that elongation pressure of 20,
 30, and 40 pounds per square inch gave rise to a static force
 of 2.00 at the 1-inch position. Elongation pressure of
 50, 60, and 70 pounds per square inch gave rise to a static
 force of 2.44 at the 2-inch position. The 2 and 4-inch
 positions were given in the same manner, and the following
 at 2.8 and 3.1 were obtained. Elongation pressure of
 70, 80, and 90 pounds per square inch gave rise to
 the 5-inch position, and 90, 100, and 110 pounds per square
 inch were used at the 6-inch position. It was found that
 force certain elongation pressure the same amount of any
 position could not be obtained. Since the matrix did not
 have a diameter attached to its wall, these high
 elongation pressures are to be obtained and about 90%

closely to those given in reference 5.

After the static probe Mach number calibration (Figure 1) was made at the various positions in the nozzle, the probe that held the small platinum wire was placed in position. The 0.003-inch platinum wire on this probe was lined up just opposite the static hole in the static probe. With the wire and plate at 0.25-inch spacing between them inserted in the nozzle at the various positions, runs were made as described in the preceding paragraph. Using this configuration, it was found that the same static pressures as obtained with the static probe alone were obtained at any position using corresponding stagnation pressures, thus showing no effect of the glow probe on static pressure and Mach number at locations under investigation.

With the probe spacing of 0.25-inch and the stagnation pressures necessary to produce the Mach number at any given position, runs were made at the various positions in the tunnel. The same procedure was followed for a 0.125-inch spacing. Ammeter and voltmeter readings were recorded during each run.

Since runs were made as rapidly as possible, it was assumed that for any run the temperature remained constant. Also, dry air (-400 F.) was used throughout the investigation.

A vacuum jar was used to determine pressure effect on the glow discharge at zero Mach number. The

closely to those given in statement D.

After the static probe was moved following

(Figure 1) was done at the various positions in the

canals, the probe was held into each position with the

finger in position. The 0.005-inch distance was on the

probe was lined up just opposite the static probe in the

static probe. With the wire and pins at 0.05-inch

spacing between them located in the canals at the various

positions, some were as described in the preceding

paragraph. Using this method, it was found that

the same static pressure is obtained with the static

probe alone was obtained at any position with the static

the static pressure, some showing no flow at all

five probe on static pressure was each shown at various

static investigation.

With the probe spacing of 0.05-inch and the

static pressure pressure necessary to produce the flow shown

at any given position, some were one of the various

positions in the canals. The flow pressure was followed

for a 0.05-inch spacing. Another and different results

was recorded using zero flow.

Since some were made as highly as possible, it

was assumed that for any one the static pressure was

constant. Also, the air (0.05 inch) was used throughout

the investigation.

A system of air was used to determine pressure

effect on the flow pressure at each static position. The

plate and wire used in the vacuum jar were made of the same material and were the same size. Various absolute pressures were maintained in the jar, and ammeter and voltmeter readings were obtained. Dry air, often ventilated to avoid ionization, was used in the vacuum jar. Figure 2 gives data obtained from this test.

plays and also used in the various (a) also made of the
 more material and were the same size. (b) also made of
 (c) also made of (d) also made of (e) also made of
 (f) also made of (g) also made of (h) also made of
 (i) also made of (j) also made of (k) also made of
 (l) also made of (m) also made of (n) also made of
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TEST DATA (EXPLANATION OF)

Figure 1 shows the Mach number versus the distance along the nozzle. The Mach number was determined by a static probe connected to a mercury manometer. The stagnation pressure was read directly from a pressure gage. If the stagnation pressure, the static pressure, and the barometer reading are known, Mach number can be easily determined. Isentropic flow was assumed upstream and downstream (but not through) the normal shock wave.

Figures 1 through 7 give microamperes versus volts at various Mach numbers ranging from zero to 3.1. The space between the plate and the wire was 0.25-inch. These curves show that the glow discharge is definitely dependent on pressure.

Figures 8 through 12 give absolute pressures versus volts at various current flows. The data for these curves were obtained from the microamperes versus volts curves (Figures 1-7).

The final curve, Figure 13, shows the effect of Mach number. Here microamperes versus volts at constant absolute pressure were plotted. After studying these curves, it can be readily seen that the glow discharge is velocity dependent. It can be seen that all curves from $M = \text{zero}$ to $M = 2.8$ have the same general trend, but the $M = 3.1$ curve is different. This is probably due to experimental errors and to poor supersonic airflow at the 4-inch position. Nevertheless, all the

[illegible]

Figure 2 shows the results of the analysis. The results show that the mean score for the control group was 1.0, while the mean score for the intervention group was 1.5. The results also show that the mean score for the control group was 1.0, while the mean score for the intervention group was 1.5.

These drives were obtained from the Minneapolis version of the Minnesota 1-5.

THE 4 LINE 4 BIRDS, 3.5 INCHES, 1941-42

[illegible]

curves show the same general trends and indicate that the Mach number has an effect on the electrical glow discharge.

The remaining curves, Figures 13 through 24, show test data under the same condition as above except that the spacing of the plate and wire was reduced to 0.125-inch. Again it can be seen that the electrical glow discharge is pressure and Mach number dependent. However, this time the Mach number curves did not plot in the same sequence. This is partly due to experimental errors, and it is expected that at the 0.125-inch spacing there is some airflow interference between the plate and the wire, even though it did not show up on the static readings. These curves, even though they don't follow in sequence, show a general trend which indicated that the glow discharge is dependent on Mach number.

Figure 34 shows a spark photograph of the nozzle blocks at a Mach number of zero. It can be seen that the channel walls are fogged up; this is due to poor glueing of the side plates to the nozzle blocks, indicating that the glue had run down the walls of the nozzle. The black heavy line below the channel is a tape measuring device for placing probes at exact position in the nozzle.

Figure 35 shows the same nozzle with supersonic airflow at a Mach number of 2.81. Shock waves at the 4-inch position can be seen. Also, at about the 4-inch position the flow starts to separate, and by the time it

either end of the same general form and instead of

the short member has an effect on the electrical glow

discharge.

The two large wires, which is shown in

then sent back under the same conditions as above except

that the spacing of the plates and wire was reduced to

0.125-inch. Again it can be seen that the electrical

glow discharge is prominent and much more prominent.

However, this time the short member seems to be

in the same position. This is partly due to experimental

errors, and it is expected that at the 0.125-inch spacing

there is some slight lateral movement between the plate and

the wire, even though it is not one of the wires

used. These errors, even though they are of the

in nature, are a general trend which indicates that

the glow discharge is dependent on these factors.

Figure 10 shows a series of photographs of the discharge

glow at a short member of wire. It can be seen that the

discharge is not uniform; this is due to poor spacing

of the wire plates to the wire member, indicating that

the glow has been down the wire of the member. The glow

heavy line across the channel is a type of electrical

for glowing gases at various positions in the channel.

Figure 11 shows the same discharge with a different

spacing of a short member at 0.125-inch. Again it can be

seen that the glow is not uniform. Also at about 0.125-inch

spacing the line across is prominent, and of the line is

reaches the end of the nozzle it appears to have separated almost completely. Due to the cloudy sides of the channel nothing else can be seen.

Figure 36 shows the same nozzle block with supersonic airflow at a Mach number of 2.81, but this time the probes are inserted in the nozzle. The spacing between the plate and wire was 0.25-inch. Here it appears that the probes have helped the flow, but again due to reflection through the top wall of the channel and cloudy channel walls, little of importance can be seen. Even though the flow appears better with the probes inserted, the static probe manometer readings indicated that ^{at} the 4-inch position separation and turbulent flow exists.

Since this experimentation was the first exploration of the supersonic flow by means of sharp point glow discharge, the establishment of methods, trends, limitations, and possible expectations for this type of flow study was more important than finality of results. At the start of the investigation it was not possible to predict in which direction to concentrate and, therefore, a flexibility in general of instrumentation was more important than fine accuracy of any one item in particular, but even with this procedure, the accuracy of all test data is limited only by the type of instrumentation used and the accuracy with which it was read. Considering the type of gages and electronic equipment used, an overall

position the end of the vessel is shown as being supported almost completely. Use for the study of the vessel's holding area can be seen.

Figure 50 shows the same vessel from a different

perspective, showing a small number of 2.0, but this

time the vessel was located in the vessel. The vessel

appears the vessel was with one 2.0-inch. Part of

appears that the vessel was being held in place, but again

due to reflection through the top wall of the vessel and

during normal use, little or no reflection can be seen.

Even though the line appears to be the vessel

positioned, the study of the vessel's position is

that the vessel is in a position of reflection and

exists.

Figure 51 shows the vessel's position as the first ex-

position of the vessel's position by means of a small

line diagram. The vessel's position is shown, showing

limitations, and possible variations for this type of

the study of the vessel's position is shown, showing

At the end of the vessel's position is shown, showing

position in which the vessel is shown, showing

a diagram of the vessel's position is shown

position of the vessel's position is shown, showing

but even with this position, the vessel's position is

and is limited only by the line of the vessel's position

and the vessel's position is shown, showing

type of vessel and its position is shown, showing

accuracy of all test data is approximately 95 percent.

Account of all last year is approximately as follows.

The first part of the year was very dry and hot.

The second part of the year was very wet and cold.

The third part of the year was very dry and hot.

The fourth part of the year was very wet and cold.

The fifth part of the year was very dry and hot.

The sixth part of the year was very wet and cold.

The seventh part of the year was very dry and hot.

The eighth part of the year was very wet and cold.

The ninth part of the year was very dry and hot.

The tenth part of the year was very wet and cold.

The eleventh part of the year was very dry and hot.

The twelfth part of the year was very wet and cold.

The thirteenth part of the year was very dry and hot.

The fourteenth part of the year was very wet and cold.

The fifteenth part of the year was very dry and hot.

The sixteenth part of the year was very wet and cold.

The seventeenth part of the year was very dry and hot.

The eighteenth part of the year was very wet and cold.

The nineteenth part of the year was very dry and hot.

The twentieth part of the year was very wet and cold.

The twenty-first part of the year was very dry and hot.

The twenty-second part of the year was very wet and cold.

The twenty-third part of the year was very dry and hot.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that an electrical glow discharge when inserted in supersonic airflow has the following characteristics:

1. The glow current is definitely pressure sensitive.
2. The glow current is dependent on velocity -- that is, any Mach number between $M = 1$ and $M = 3$ change effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and positive wire polarities.
4. Platinum wire 0.003-inch diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough glow discharge for this experiment.
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

The following recommendations are given below:

1. If lucite nozzle blocks are to be made for this tunnel, it is recommended that great care be taken in the glueing process to give clear and smooth walls.
2. Nozzle blocks should be made by the method of characteristics, thus eliminating the bad flow conditions encountered in the Laval nozzle.

LOCATIONS AND RECOMMENDATIONS

It is recommended that an additional flow rate

be added when located in appropriate areas and

following recommendations:

1. The flow pattern is relatively pressure sensitive.
2. The flow pattern is dependent on velocity. The flow is, very much dependent on velocity $N = 1$ and $N = 2$ change effects the flow pattern.
3. A higher velocity is required to maintain a flow pattern for larger velocity changes, a larger flow rate, and positive flow pattern.
4. Flow rate with 0.005-inch diameter must be used in this location because any smaller size flow rate would be too small to be used in this location.
5. Current flow rate is 10 micrometers flow rate. This is the minimum for this location.
6. The shape of the flow rate and the velocity, flow rate is most affected the current flow rate.
7. The flow pattern is also flow dependent in this location.
8. The flow changes in flow rate change in this location.
9. This location is likely to be a static pressure measuring location and possibly a flow rate location.

The following recommendations are given below:

1. If flow rate is 10 micrometers flow rate, it is recommended that flow rate be added in the flow rate to flow rate and flow rate.
2. Flow rate should be added on flow rate and flow rate. Flow rate should be added on flow rate and flow rate.

3. An extremely sensitive type of throttling valve be incorporated in the equipment to enable the operator to hold stagnation pressures more closely to the desired value.
4. An accurate means of measuring stagnation pressures be used. It is suggested that an electronic gage (strain gage) be used.
5. A mount holder for the probes should be designed so that it will give good accessibility to a change in spacing of plate and wire.
6. The two probes should be made of a strong insulating material, thus eliminating steel tubing and liquid plastic insulations.
7. A high voltage fuse should be used in the electronic equipment to avoid any voltage leakage and to protect the power supply.
8. A voltmeter and an ammeter circuit should be designed to measure the voltage and the current when the two power supplies are connected in series.
9. A tapered needle to give sharper point and enough strength to withstand air blast may be necessary and if it is not too expensive to manufacture, should be tried in the next experiments.

3. An electrically sensitive type of photoelectric cell
be incorporated in the equipment to enable the
operator to hold magnetic pressure more closely
in the desired range.
4. An automatic means of measuring magnetic pressure
have no need. It is suggested that an electric
type (strain gauge) be used.
5. A sound indicator for the probe should be designed
so that it will give good sensitivity in a
range of spacing of probe and wire.
6. The two probes should be made of a strong in-
sulating material, thus eliminating steel loading
and rigid plastic insulations.
7. A high voltage time should be used in the
electric equipment to avoid any voltage loss
the wire is broken by the probe supply.
8. A vibrator and an amplifier circuit should be
designed to measure the voltage and the current
from the two probe supplies are connected in
series.
9. A separate switch for five switch point and enough
strength as withstand wire used as an assembly
and it is not too expensive to manufacture.
should be tried in the next experiments.

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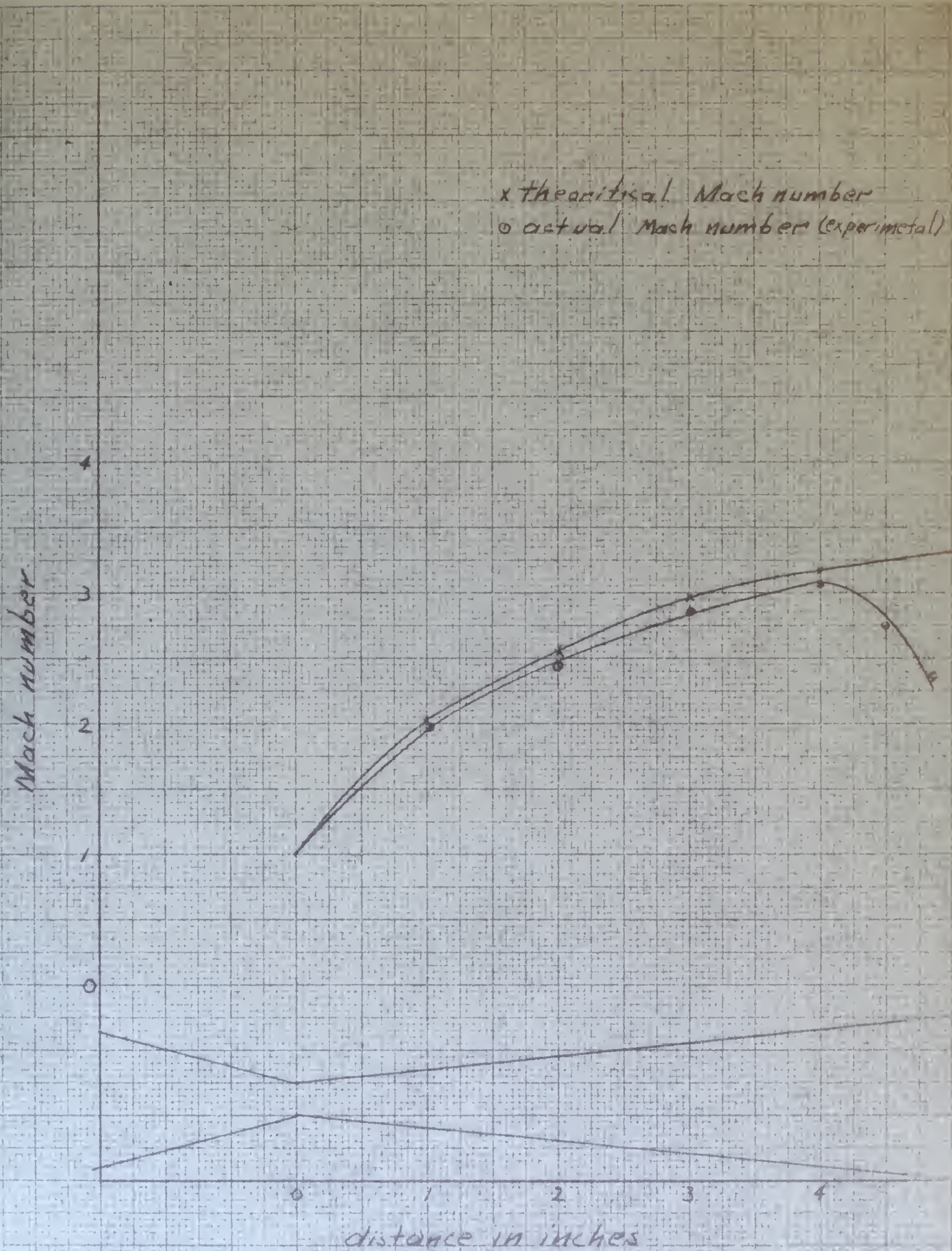


Fig-1-

Voltage VS Current for absolute Pressures
between 29.14 inches Hg and 4.12 inches Hg.

Mach number equal 0

Wire .003 platinum spacing .25 inches

Dry air

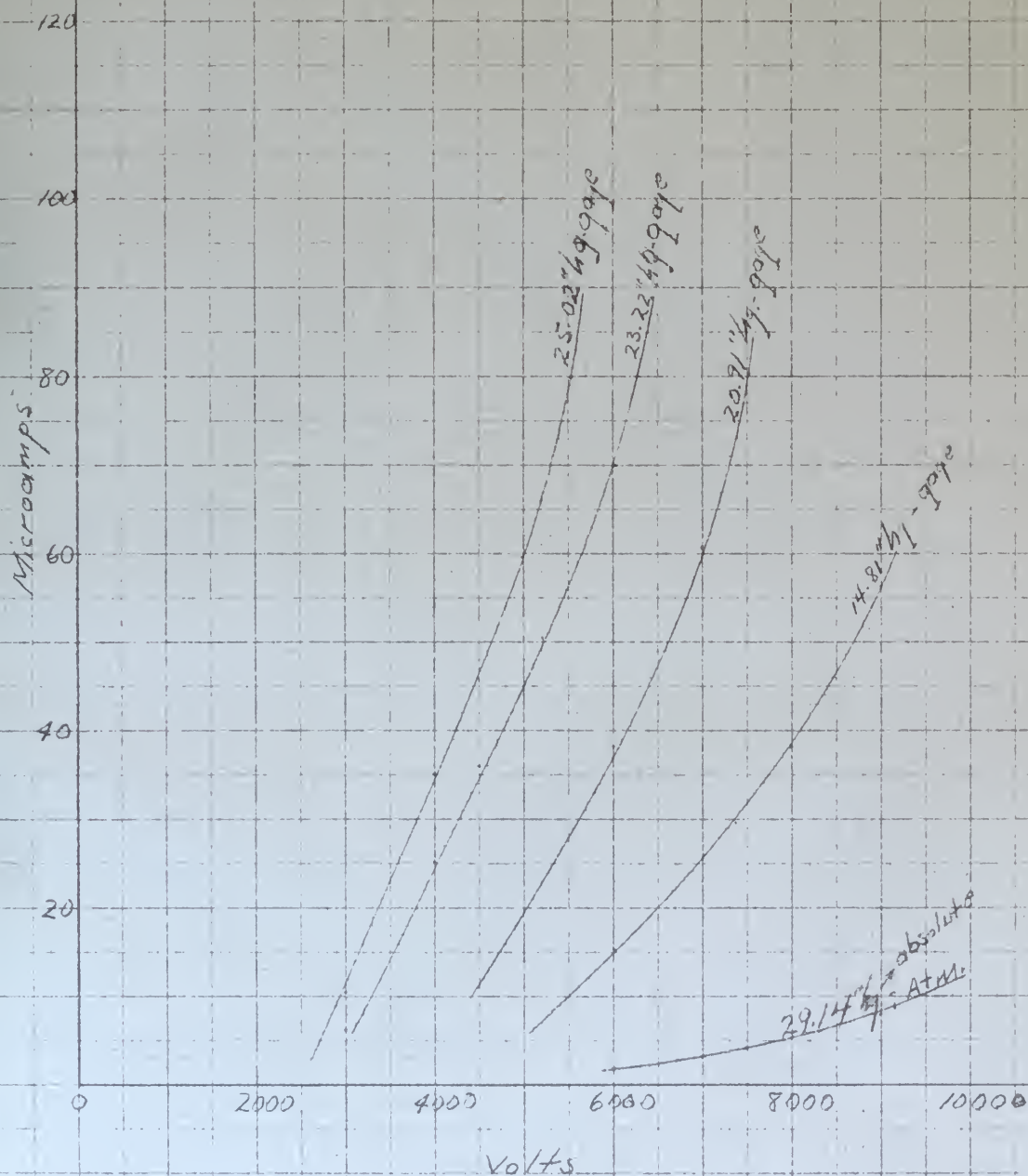


Fig-2 -

Microamps Vs Volts

Wire - .003 spacing .25 inches

Position .71 inches in nozzle

Mach Number 1.72

140 Stagnation pressure 21.0 $\frac{\text{lb}}{\text{in}^2}$ abs; static probe 5.4 $\frac{\text{lb}}{\text{in}^2}$ abs
 " " 21.8 $\frac{\text{lb}}{\text{in}^2}$ abs; " 4.3 $\frac{\text{lb}}{\text{in}^2}$ abs
 " " 27.8 $\frac{\text{lb}}{\text{in}^2}$ abs; " 4.2 $\frac{\text{lb}}{\text{in}^2}$ abs

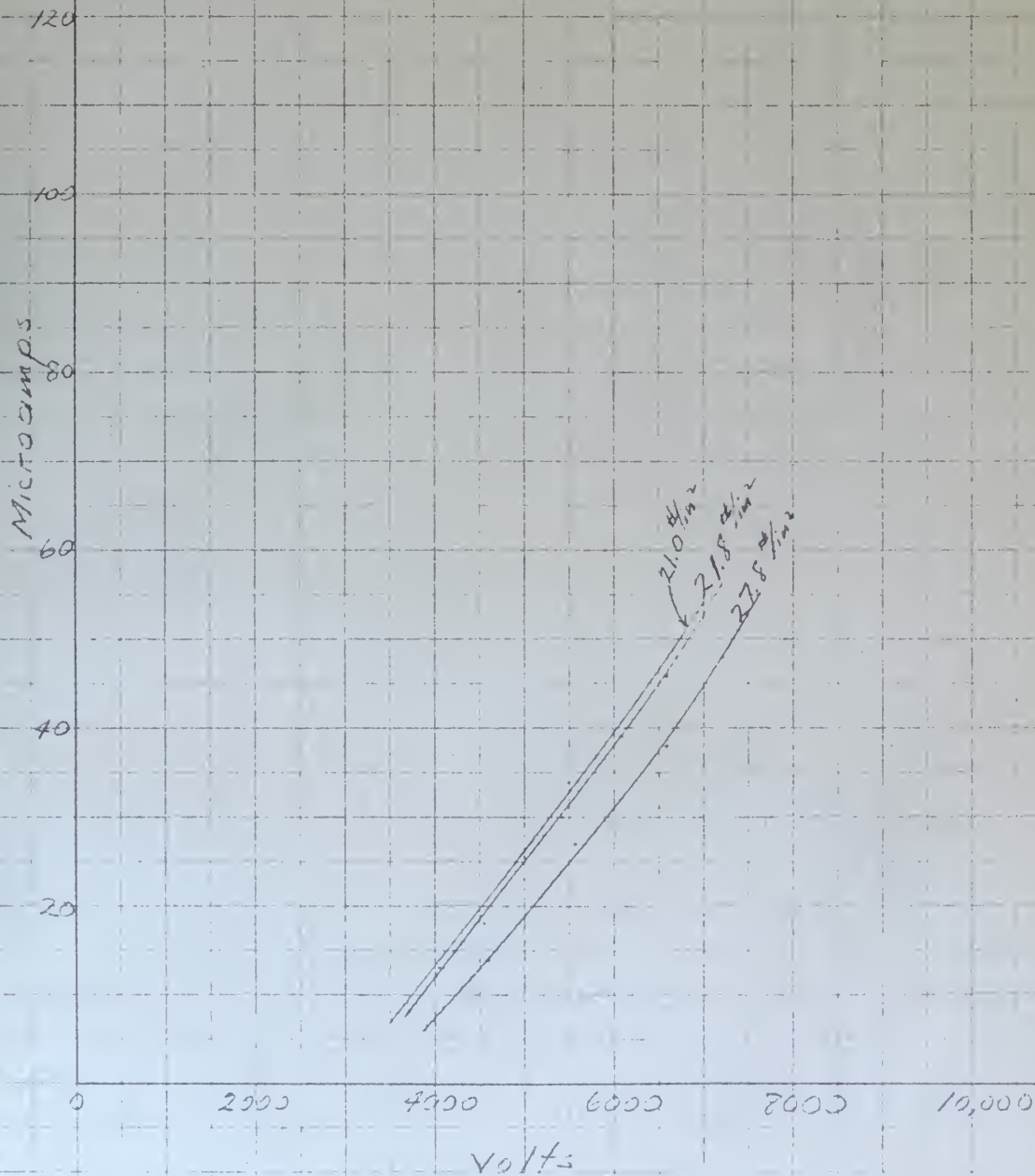


Fig-3-

Microamps vs Volts

.003 wire

.25" spacing

1" position in nozzle

Mach number = 2.08

Stagnation pressure at 25# gage; static probe 10.3 #/sq in
 " " " 30# gage; " " " 9.15 #/sq in
 " " " 40# gage; " " " 7.15 #/sq in

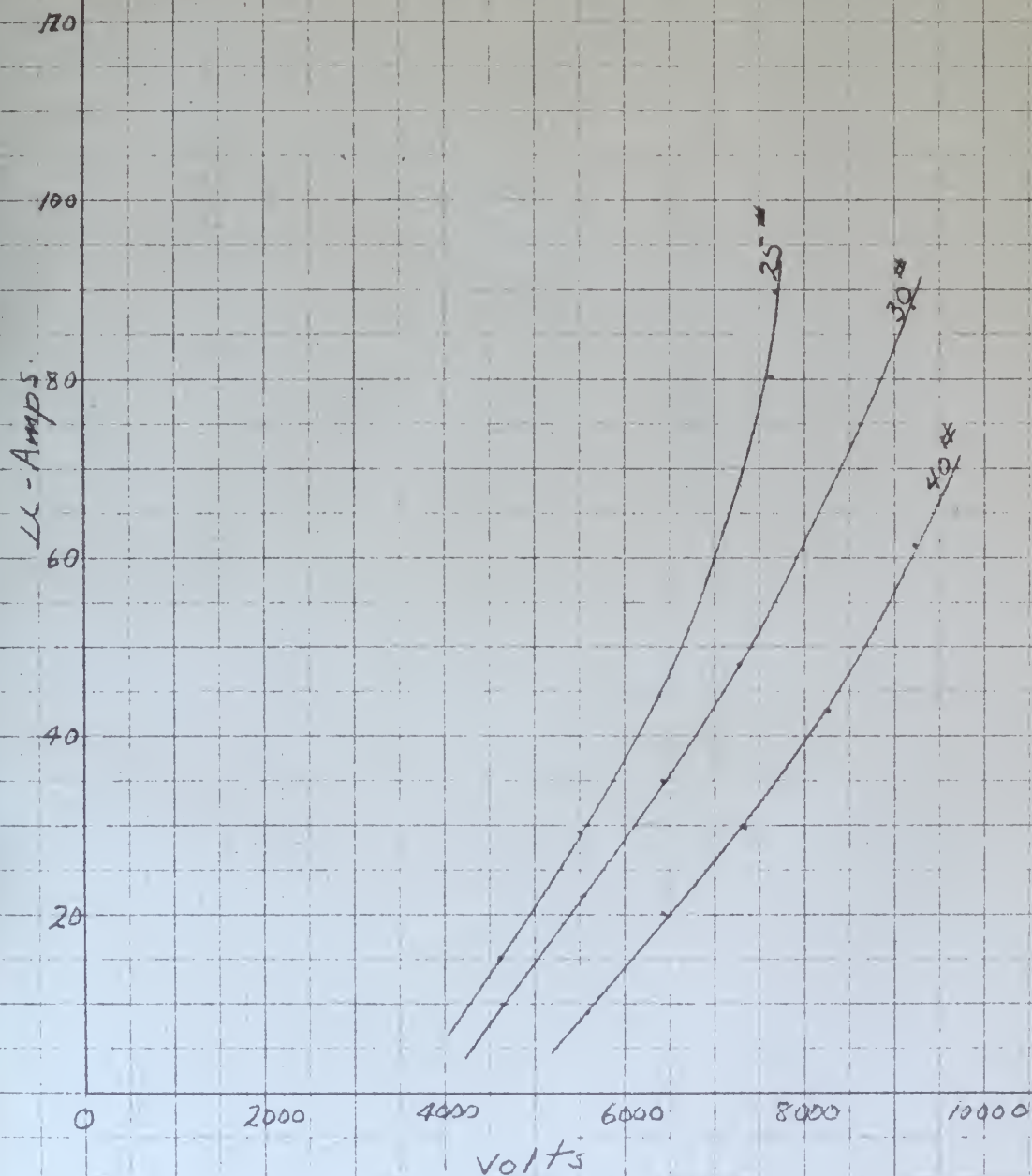


Fig-4-

Microamps Vs Volts

Wire - .003 platinum

Spacing - .25 inches

Position in nozzle 2"

Mach number = 2.49

Stagnation pressure of 40# gage; static probe 11.5# gage

50# gage; " " 10.2# gage

60# gage; " " 9.2# gage

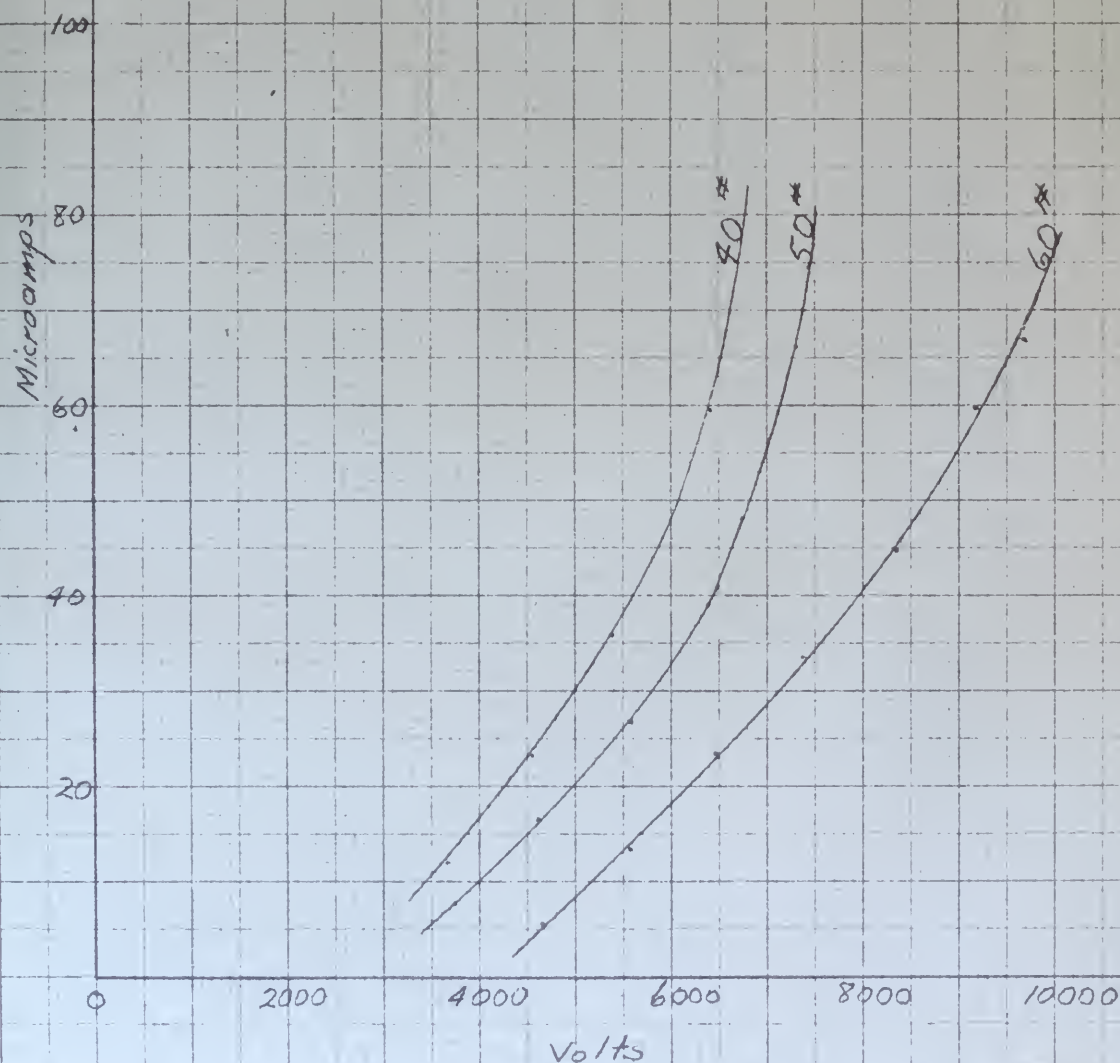


Fig-5-

Microamps vs Volts

Wire - .003 platinum

Spacing .25 inches

Position 3 inches from throat

Mach number 2.81

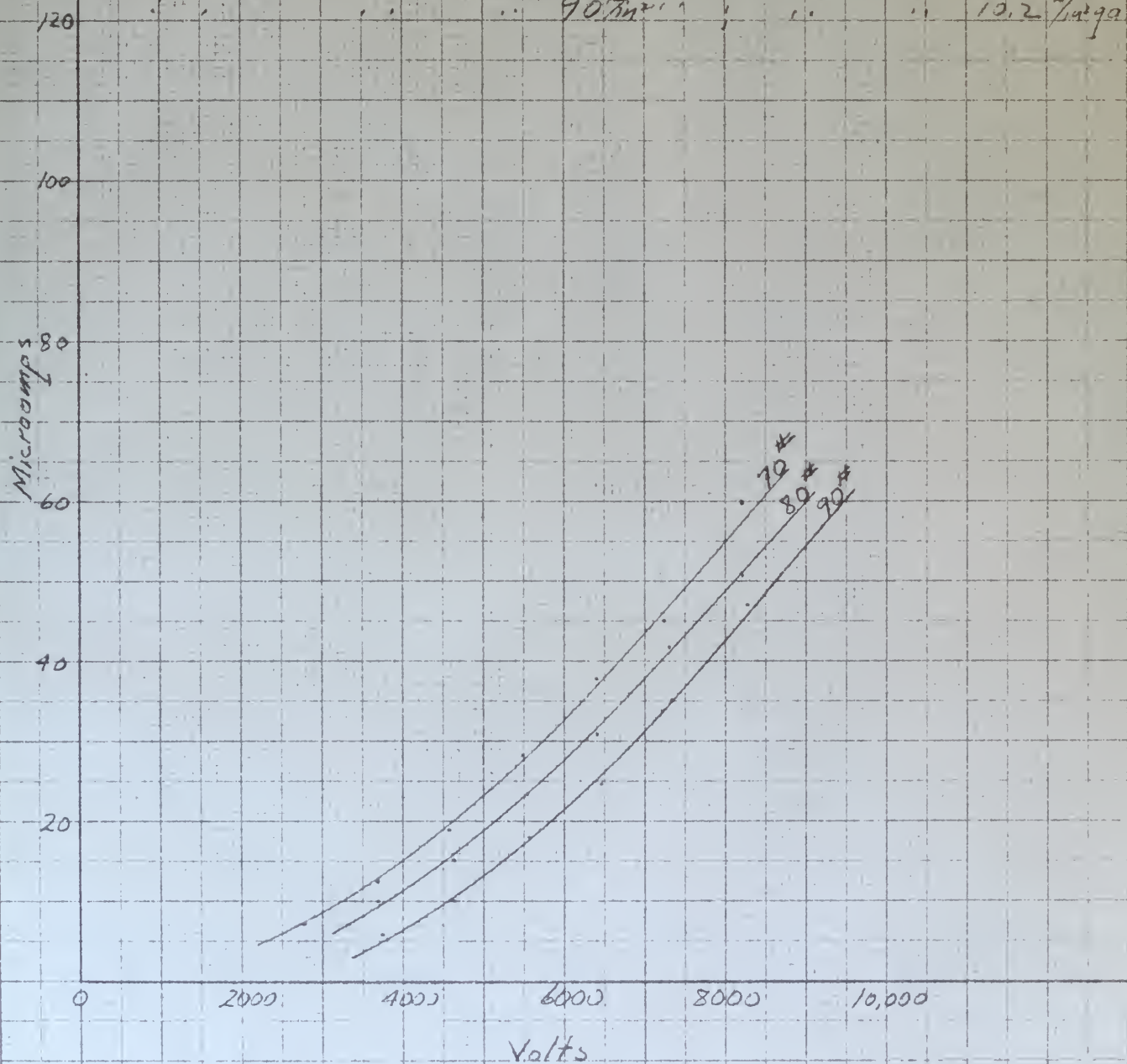
Stagnation pressures of 70th gage; static probe 16.7 #/sq. in.Stagnation pressure of 80th " " " " 16.0 #/sq. in.Stagnation pressure of 90th " " " " 15.2 #/sq. in.

Fig-6-

Microamps vs. Volts

Wire .003 platinum

Spacing .25 inches

Position in nozzle 4"

Mach number = 3.1

Stagnation pressure 90 $\frac{\text{lb}}{\text{in}^2}$ gage ; static probe 12.4 $\frac{\text{lb}}{\text{in}^2}$ gage
 " " 94 $\frac{\text{lb}}{\text{in}^2}$ " ; " " 12.1 $\frac{\text{lb}}{\text{in}^2}$ "
 " " 100 $\frac{\text{lb}}{\text{in}^2}$ " ; " " 11.87 $\frac{\text{lb}}{\text{in}^2}$ "

Microamps

140

120

100

80

60

40

20

0

2000

4000

6000

8000

10000

Volts

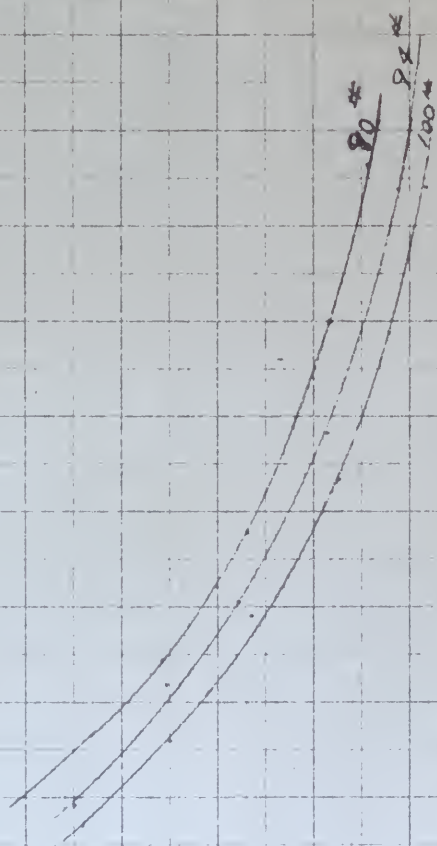


Fig-7-

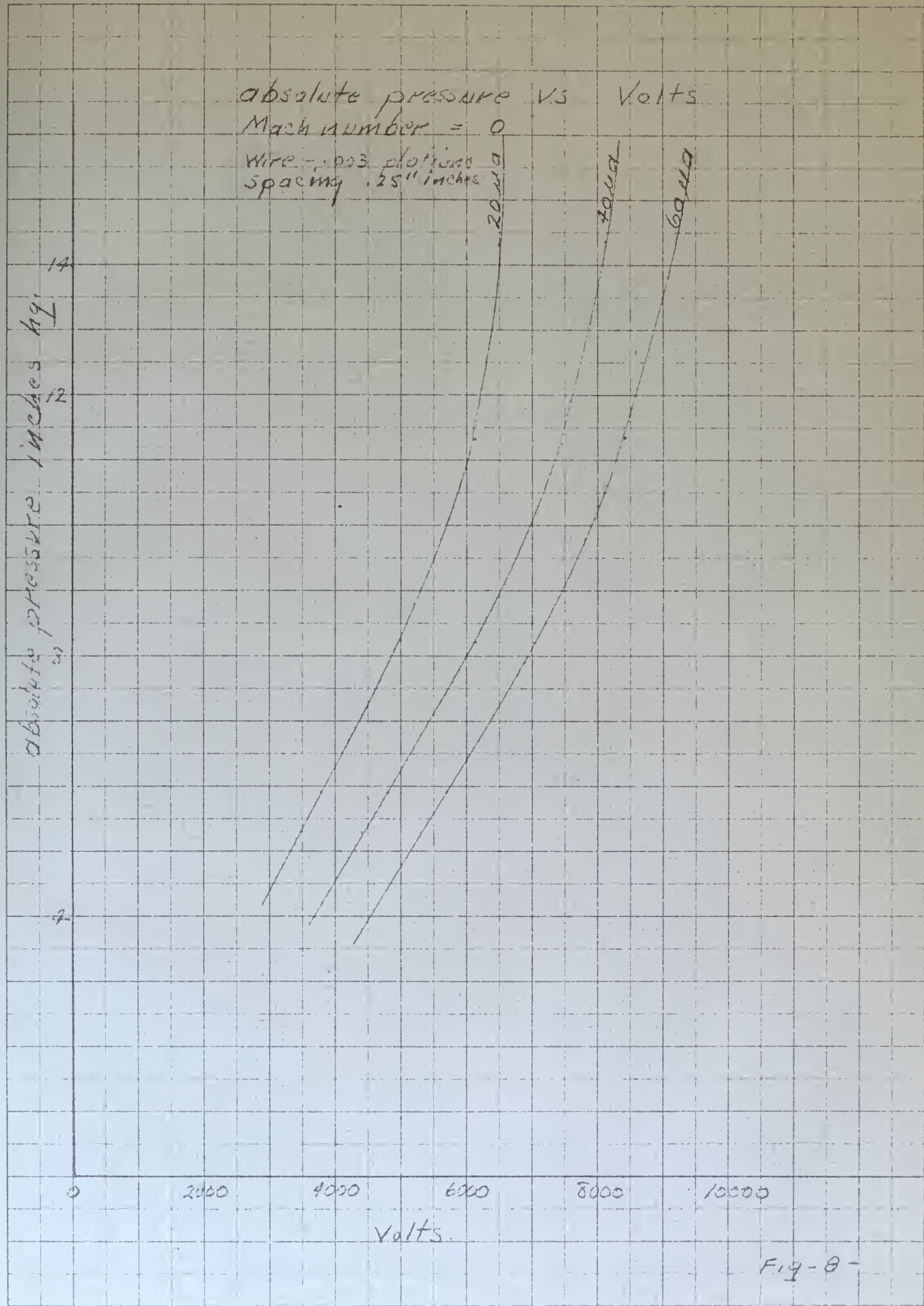


Fig-8-

absolute pressure vs Volts

Mach number = 2.08

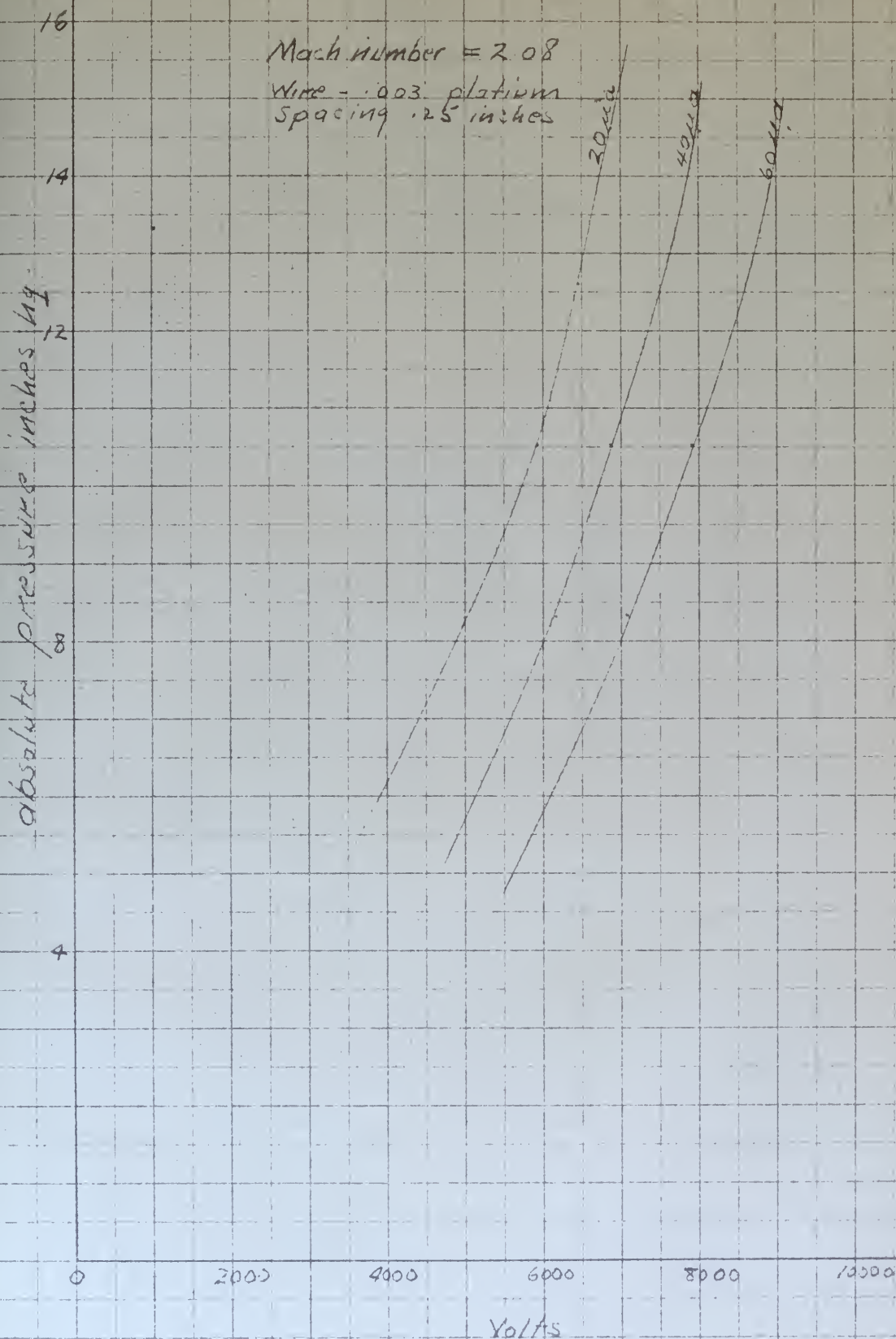
Wire = .003 platinum
Spacing .25 inches

Fig-9-

absolute pressure vs Volts

Mach number = 2.44

Wire = .003 platinum

Spacing .25 inches

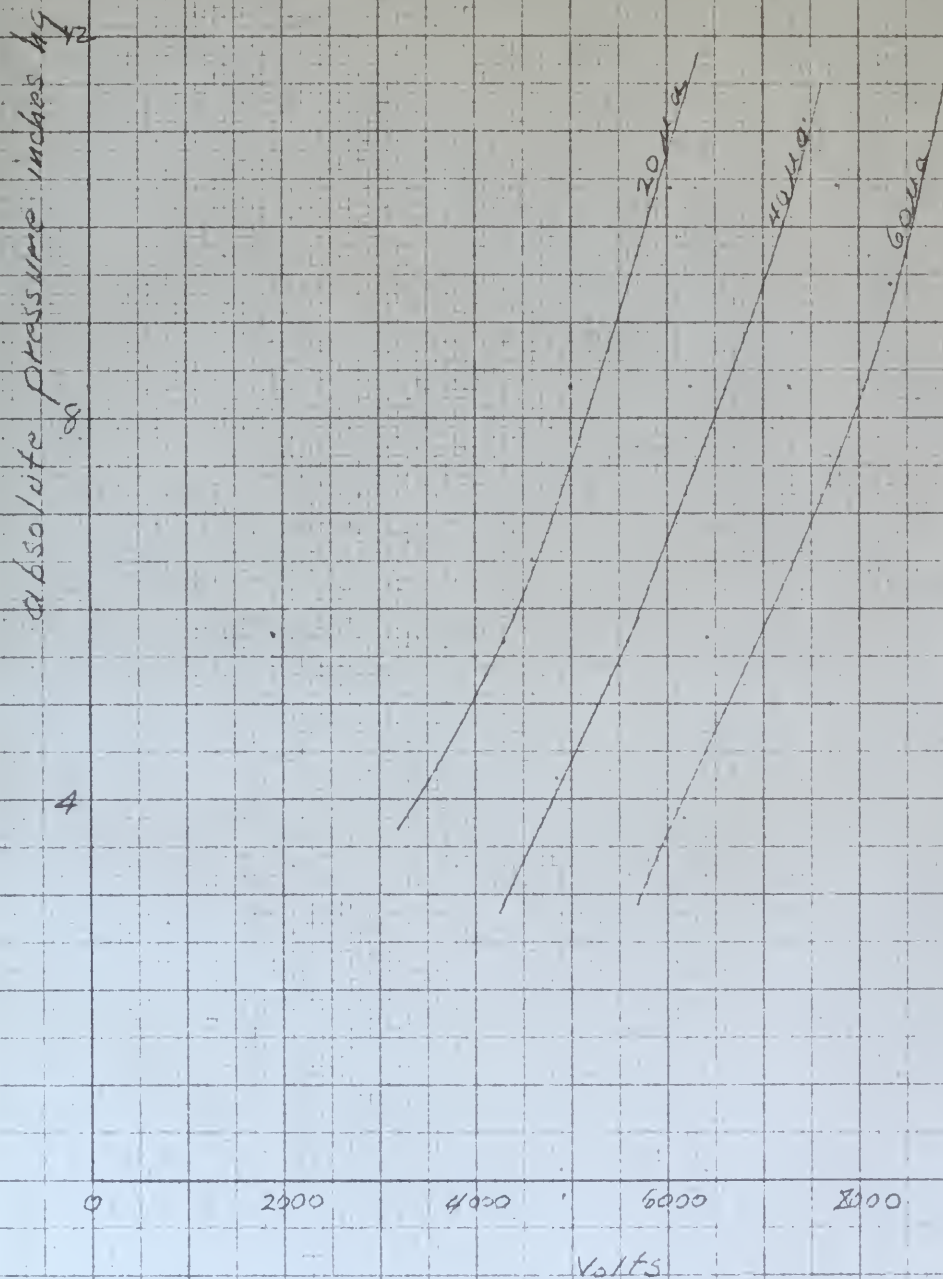


Fig-10-

Absolute Pressure vs Volts

Mach number 2.81

Wire .002 platinum

Spacing .25 inches

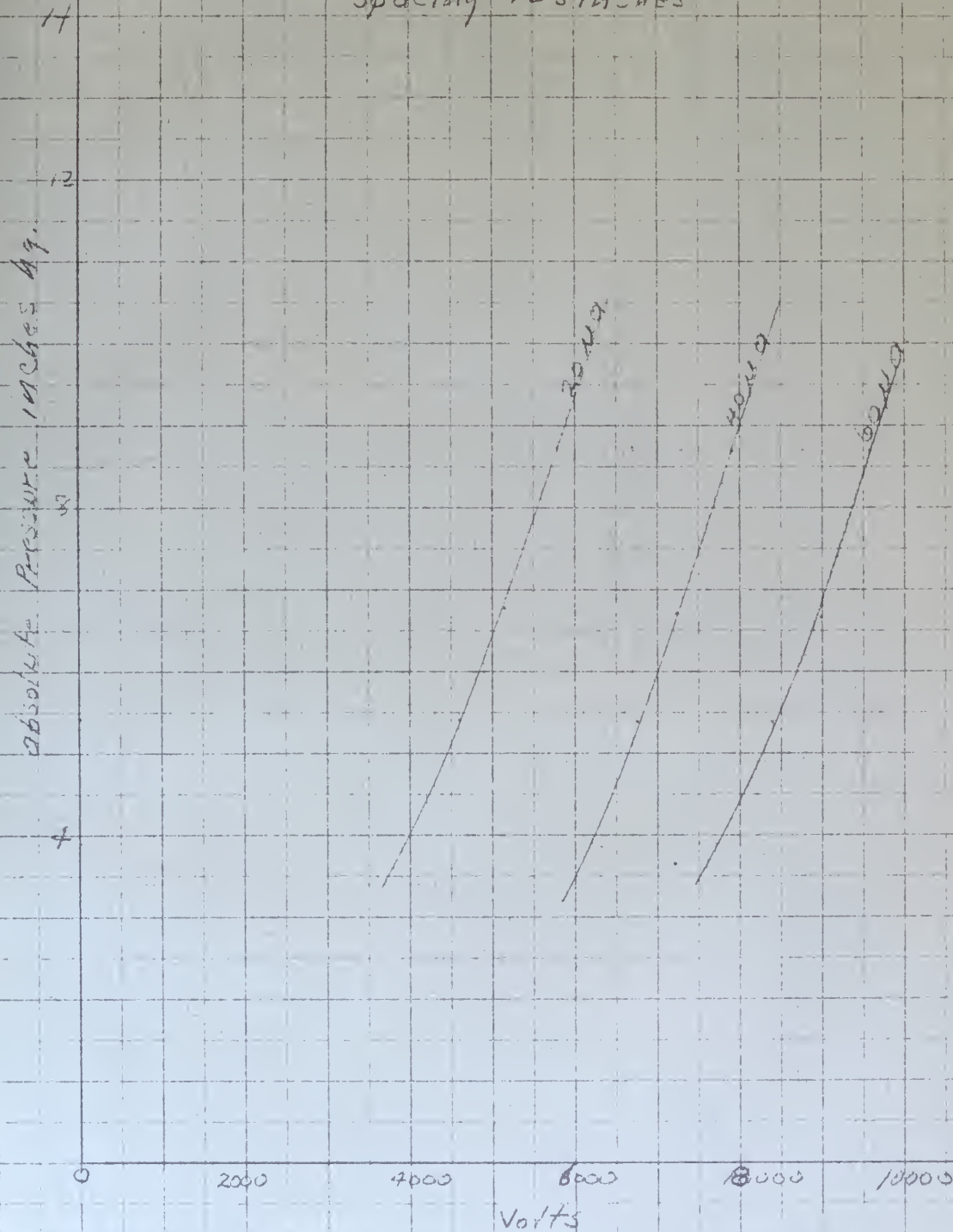


Fig-11-

absolute pressure vs Volts
 Mesh number 3.1
 Wire .003 platinum
 Spacing .25 inches

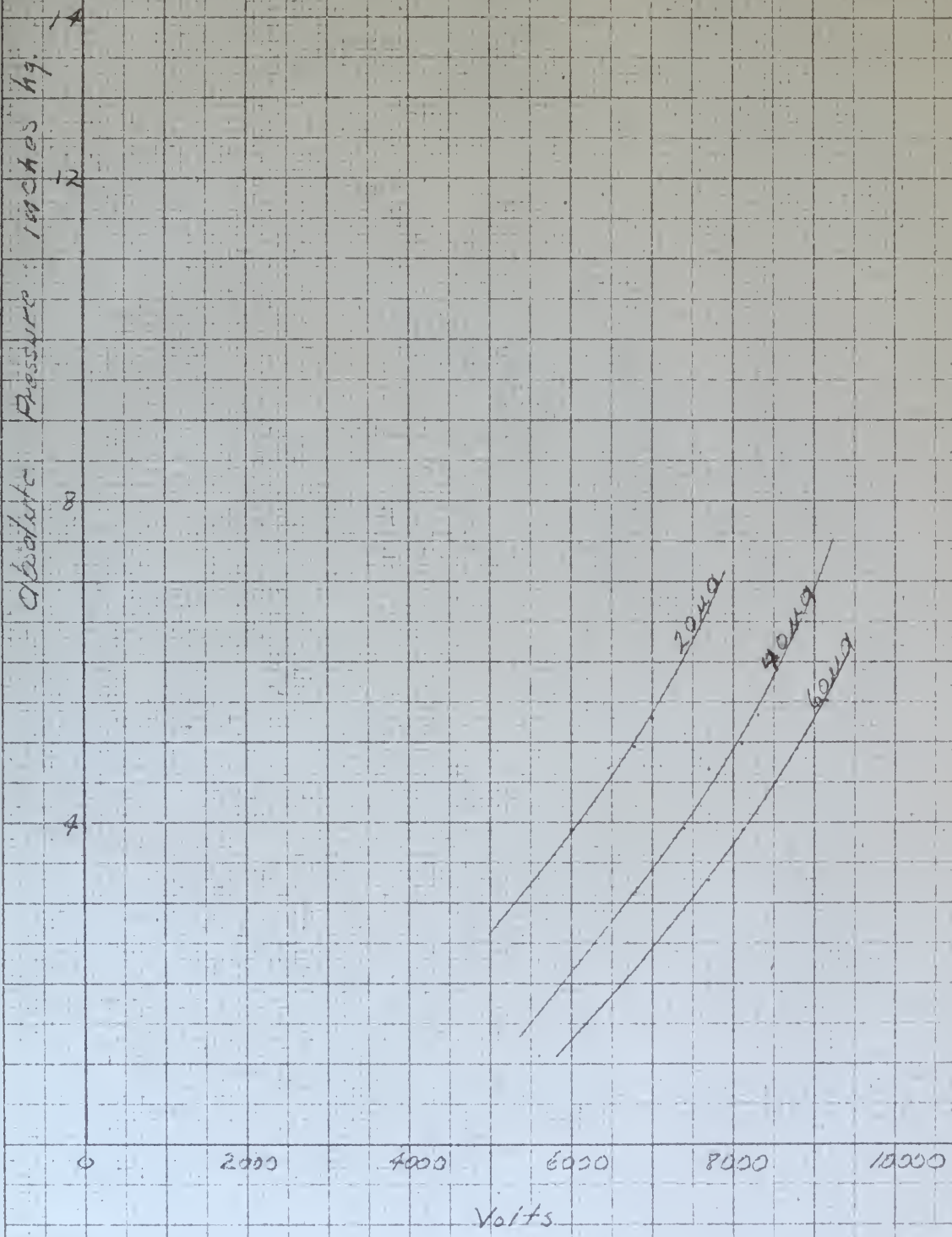


Fig-12-

Microamps vs. Volts at const. obs. pressure
absolute pressure = 5 inches hg.

Wire - .003 platinum
Spacing - .25 inches

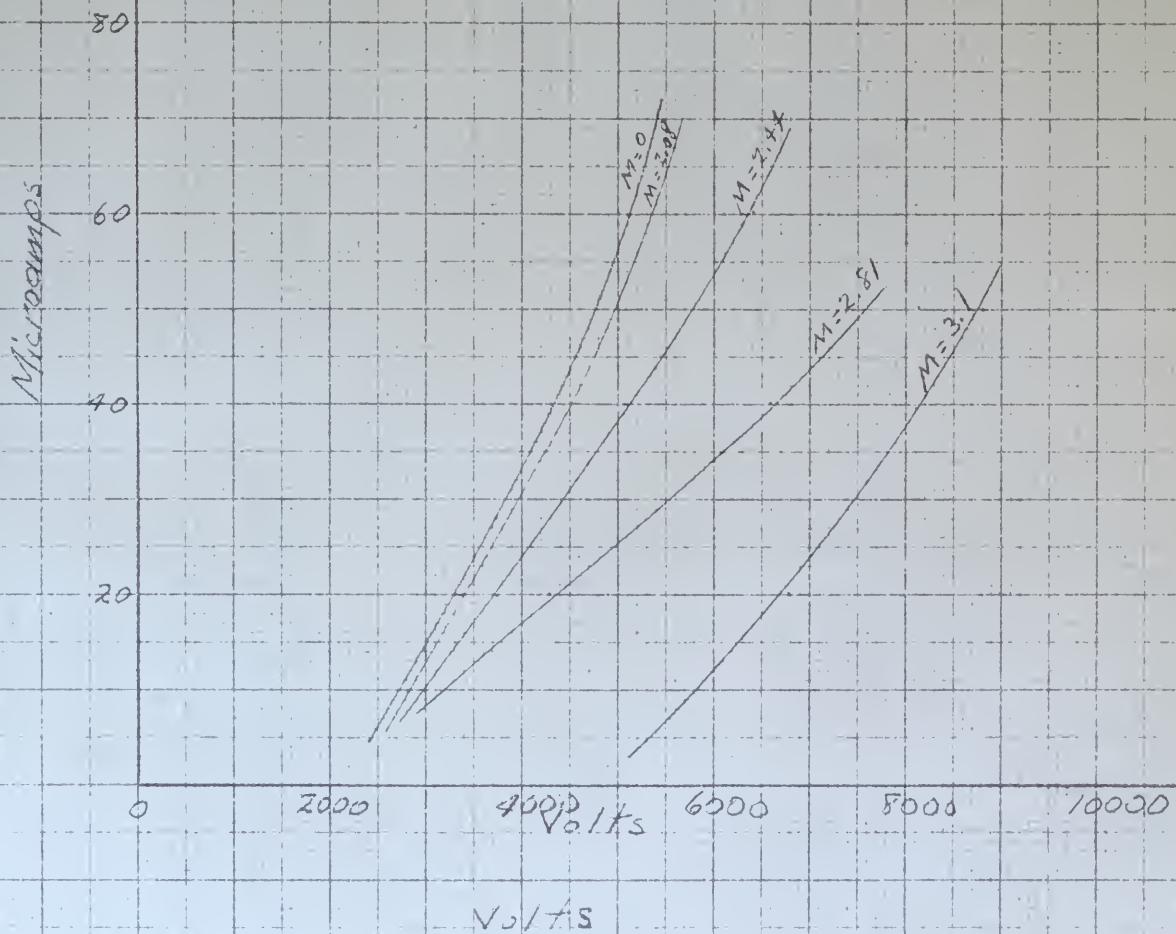


Fig-13-

Voltage vs Current for absolute pressures
between 29.14 inches Hg and 4.46 inches Hg.

Mask number equal 0

Wire .003 platinum ; spacing .125 inches

Dry air

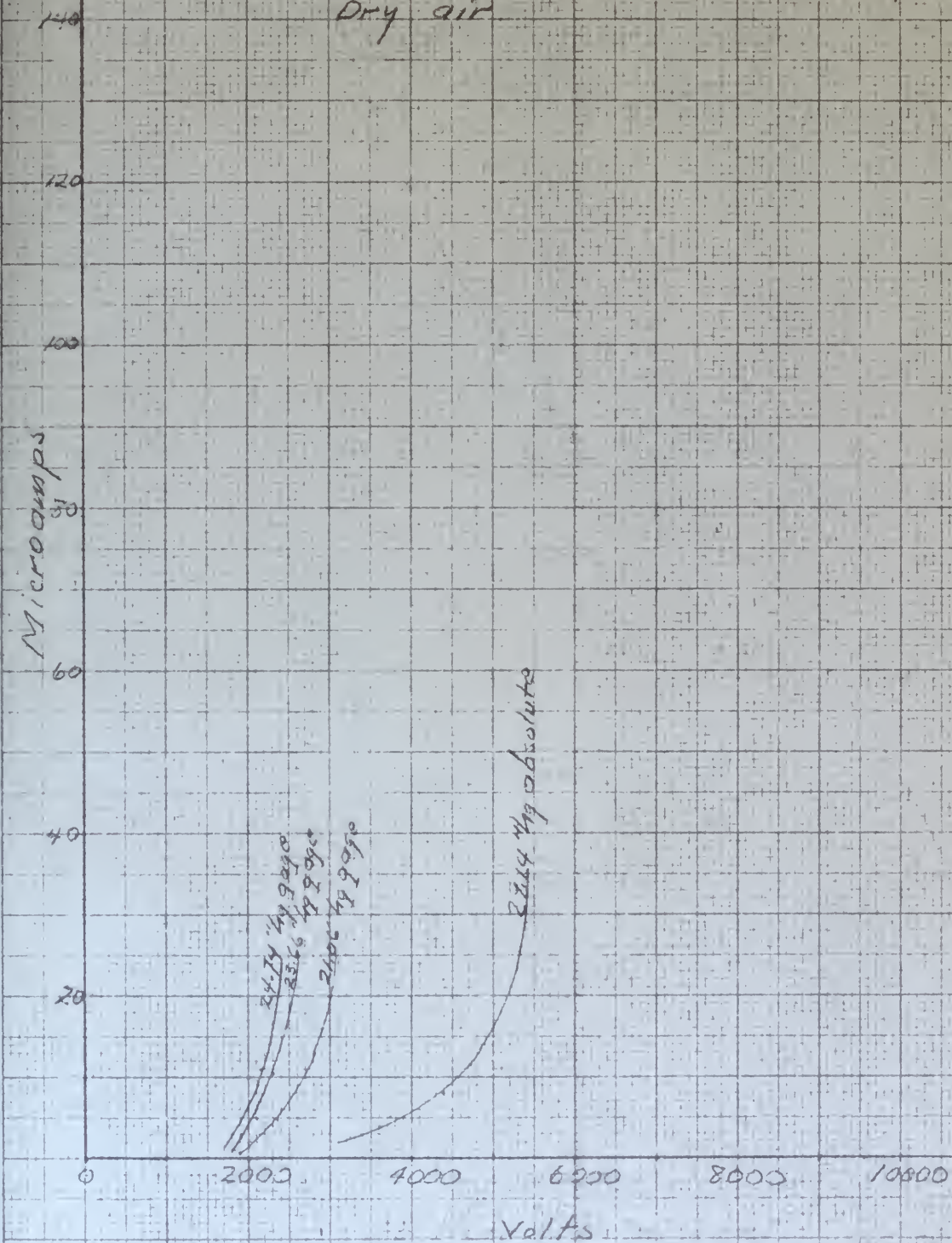


Fig - 1.4 -

Microamps vs Volts

Wire .003 platinum spacing .125"

Position .6 inches in nozzle

Mach number 1.62

Stagnation pressure	21.9 $\frac{\text{lb}}{\text{in}^2 \text{ abs}}$	Static probe	4.94 $\frac{\text{lb}}{\text{in}^2 \text{ abs}}$
"	21.2 $\frac{\text{lb}}{\text{in}^2 \text{ abs}}$	"	4.88 $\frac{\text{lb}}{\text{in}^2 \text{ abs}}$
"	26.2 $\frac{\text{lb}}{\text{in}^2 \text{ abs}}$	"	6.51 $\frac{\text{lb}}{\text{in}^2 \text{ abs}}$

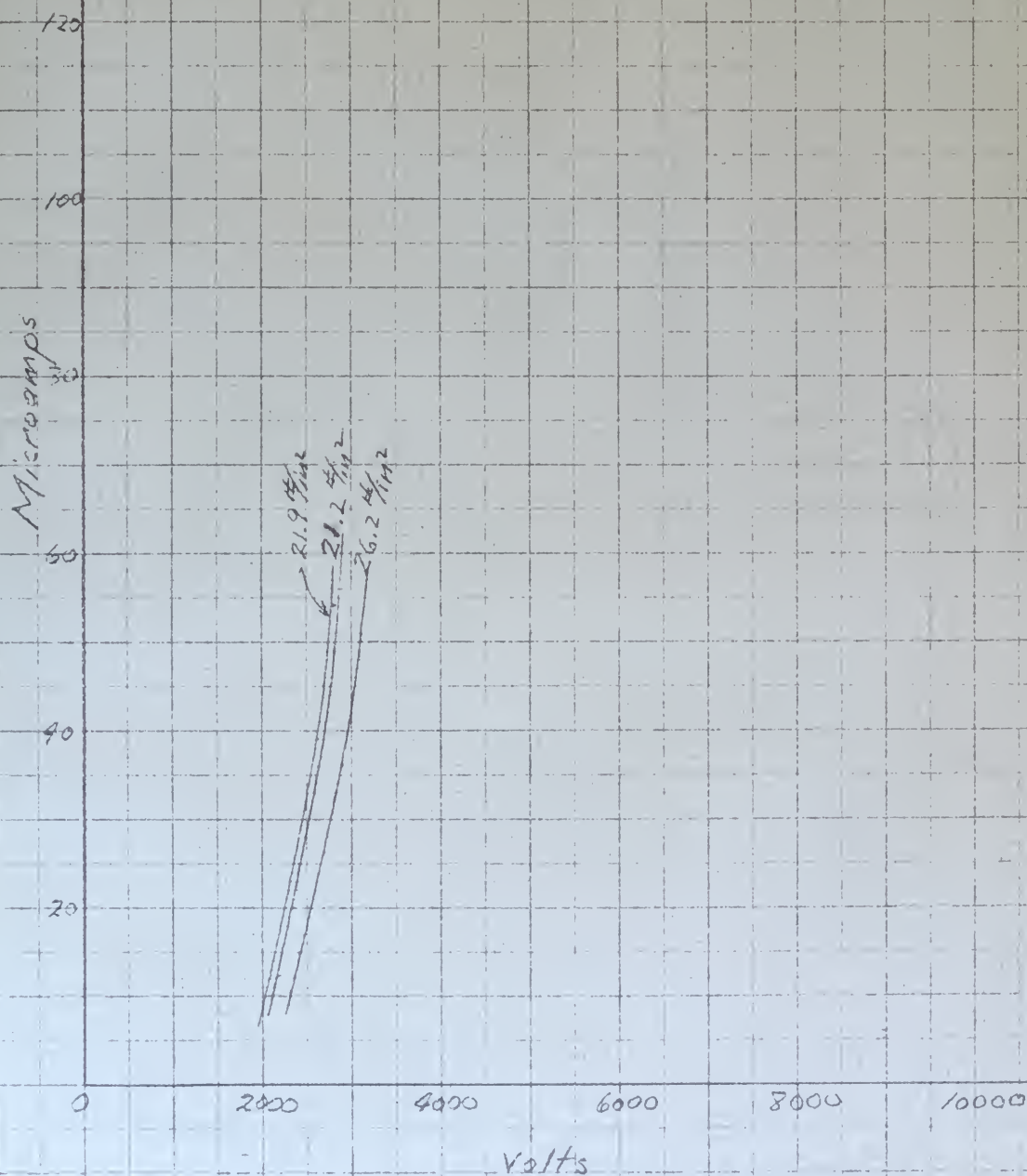


Fig-15-

Microamps VS Volts

Wire .003 platinum
spacing .125"
Position in nozzle 1"
Mach number - 2.03

Stagnation pressure at 25 $\frac{\text{lb}}{\text{in}^2}$ gage; probe (static) 10.3 $\frac{\text{lb}}{\text{in}^2}$
" 30 $\frac{\text{lb}}{\text{in}^2}$ " 1.15 $\frac{\text{lb}}{\text{in}^2}$
" 40 $\frac{\text{lb}}{\text{in}^2}$ " 7.15 $\frac{\text{lb}}{\text{in}^2}$

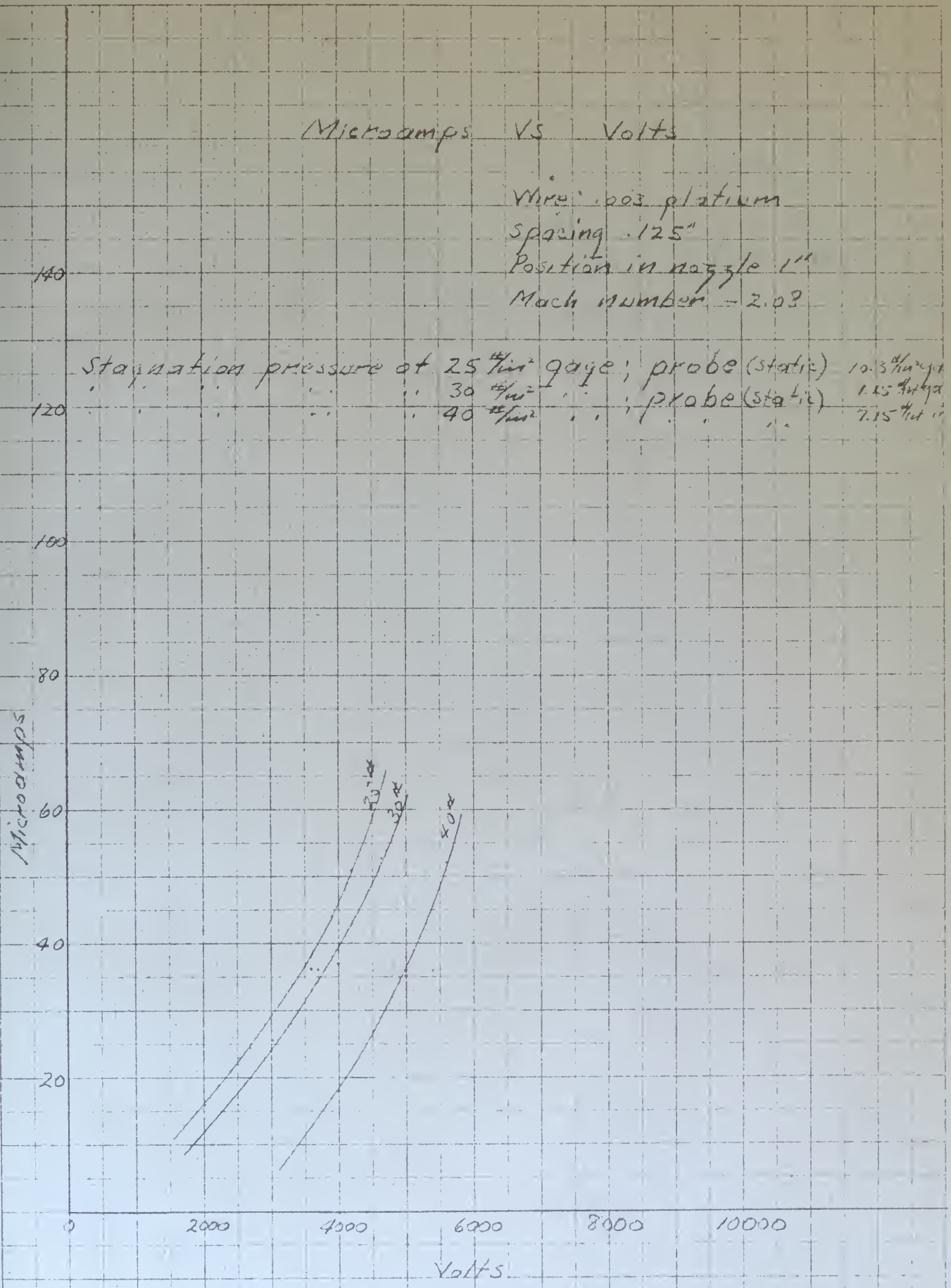


Fig-16-

Microamps vs. Volts

.003 wire platinum

.125" spacing

2" position in nozzle

Mach number 2.49

Stagnation pressure at 40 $\frac{\text{lb}}{\text{in}^2}$ gage static probe 11.5 $\frac{\text{lb}}{\text{in}^2}$ gage50 $\frac{\text{lb}}{\text{in}^2}$ 10.2 $\frac{\text{lb}}{\text{in}^2}$ 60 $\frac{\text{lb}}{\text{in}^2}$ 9.2 $\frac{\text{lb}}{\text{in}^2}$

Microamps

140

120

100

80

60

40

20

0

2000

4000

6000

8000

10000

Volts

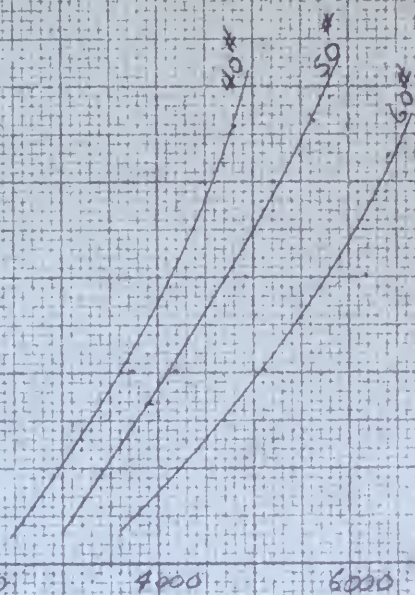


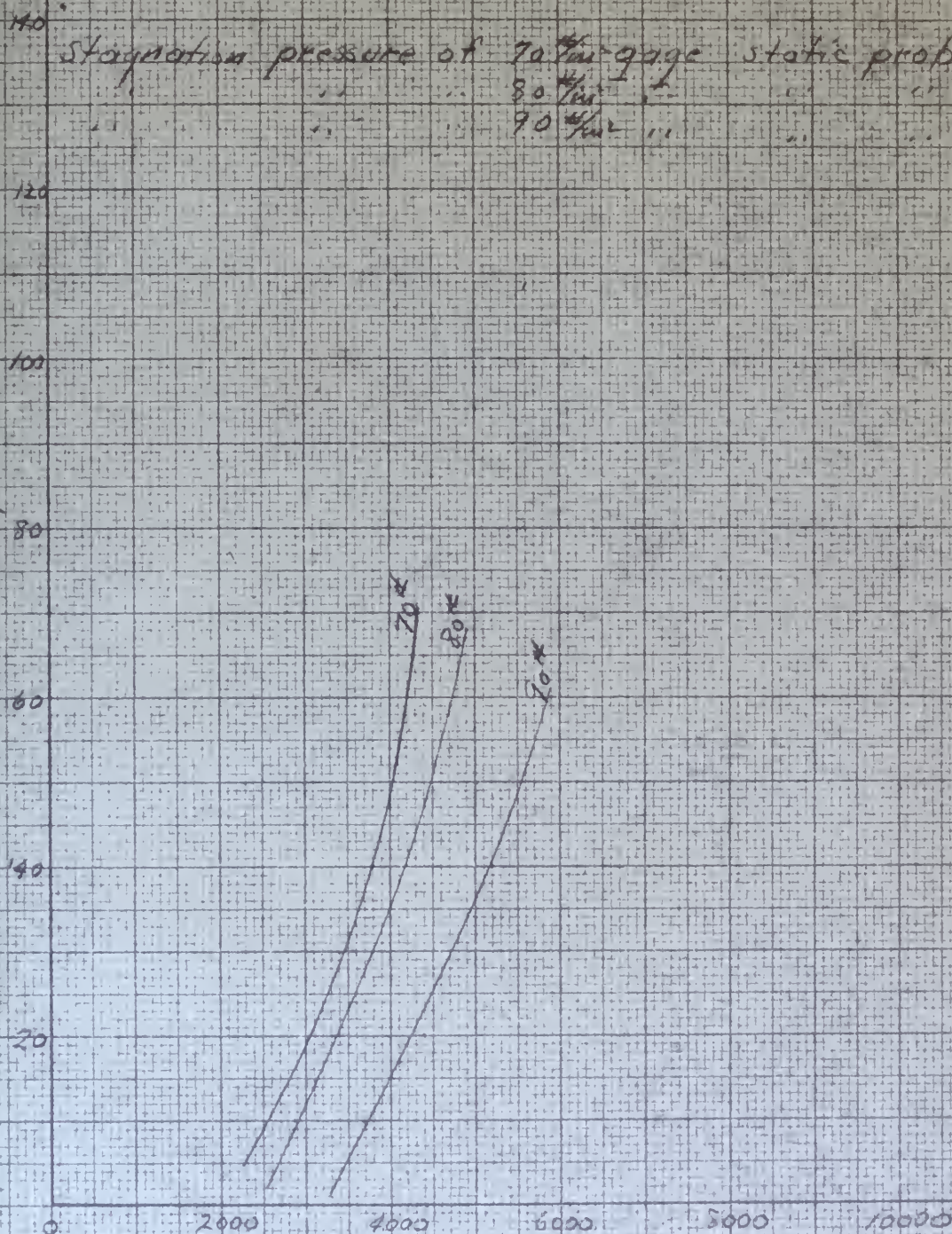
Fig-17-

Microamps VS Volts

Wica, 1003 platinum
 scaling 12.5
 Mach number 2.81
 position in nozzle 3"

stagnation pressure of 70 $\frac{\text{ft}}{\text{min}}$ gage static probe 11.7 $\frac{\text{ft}}{\text{min}}$ gage
 80 $\frac{\text{ft}}{\text{min}}$ " " 11.0 $\frac{\text{ft}}{\text{min}}$
 90 $\frac{\text{ft}}{\text{min}}$ " " 10.2 $\frac{\text{ft}}{\text{min}}$

Microamps



Volts

Fig-1B-

Microamps Vs Volts

Wire .003 platinum

Spacing .125

Mach number - 3.1

position in nozzle 4"

Stagnation pressure of 90 $\frac{\text{lb}}{\text{in}^2}$ static probe 12.4 $\frac{\text{lb}}{\text{in}^2}$
" " " 9.4 $\frac{\text{lb}}{\text{in}^2}$ " " 12.1 $\frac{\text{lb}}{\text{in}^2}$
" " " 100 $\frac{\text{lb}}{\text{in}^2}$ " " 11.57 $\frac{\text{lb}}{\text{in}^2}$

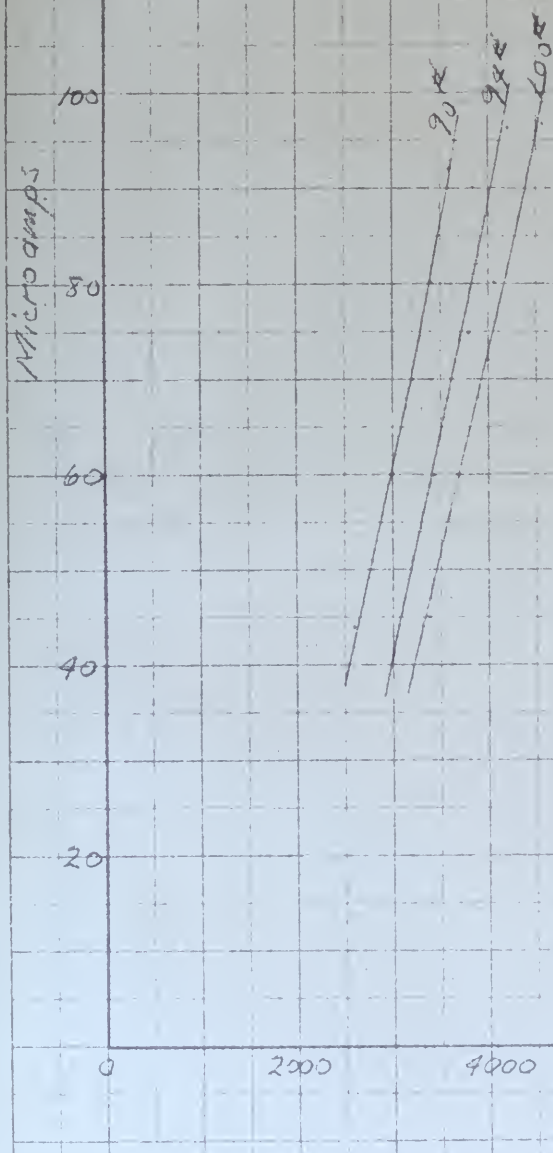


Fig-19-

absolute pressure vs Volts

Mach number = 2.08
 Spacing = 125 inches
 Wire = 003 platinum

absolute pressure inches Hg

100V

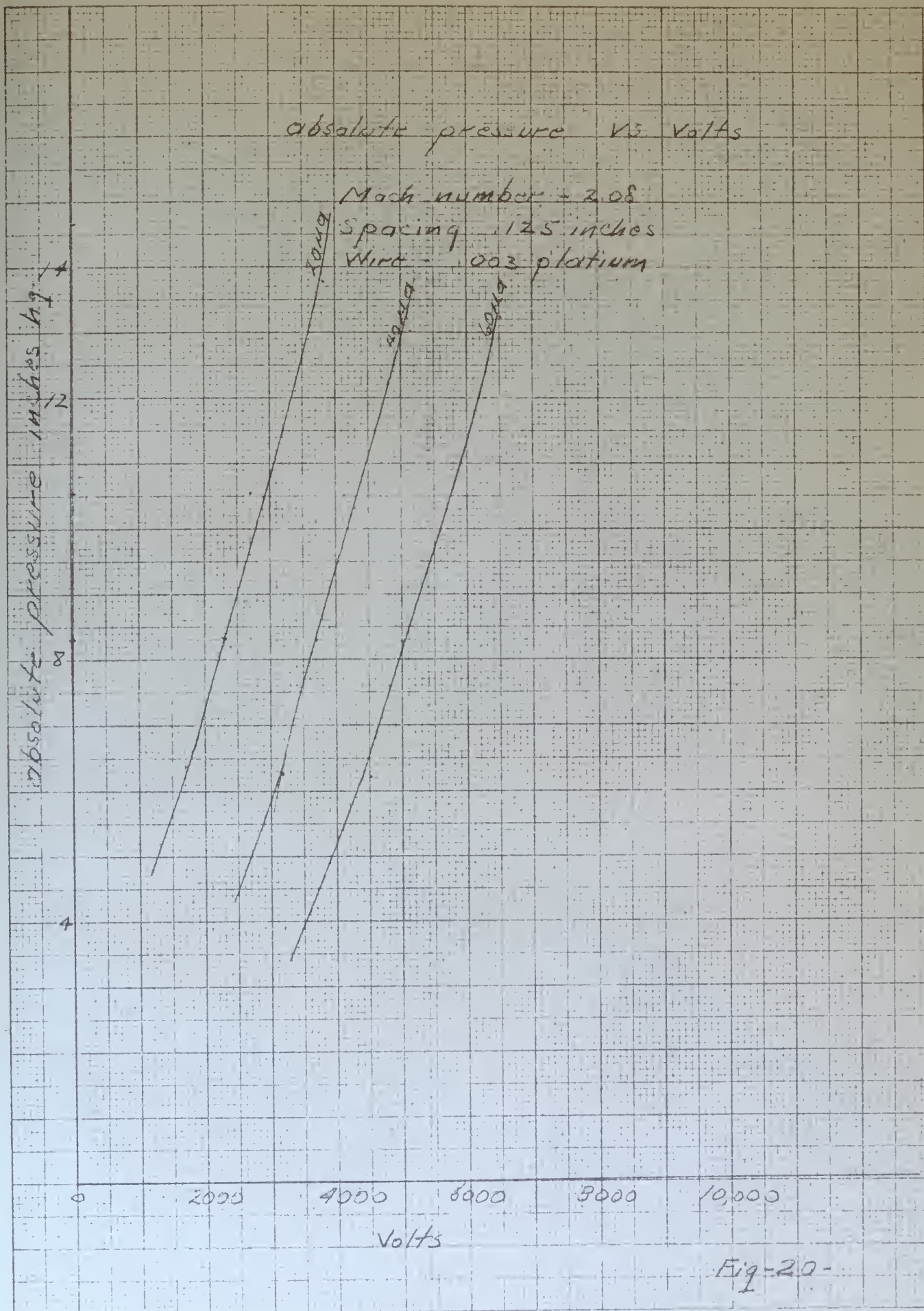
400V

600V

0 2000 4000 6000 8000 10,000

Volts

Fig-20-



absolute pressure vs Volts

Mach number 2.44

Spacing .125 inches

Wire .003 platinum

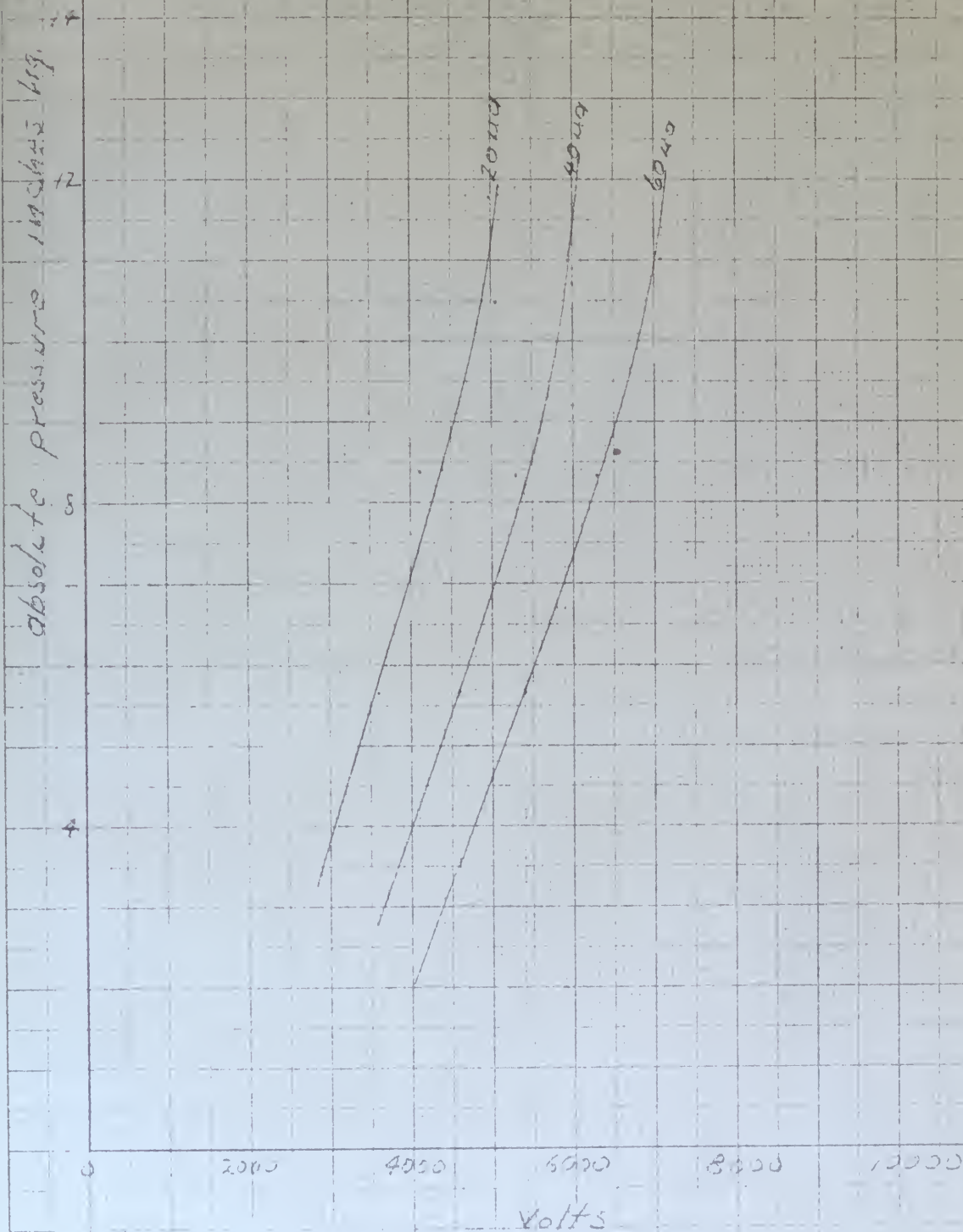


Fig-21-

absolute pressure vs. Volt

Mach number 2.81

Spacing .125 inches.

Wire .003 platinum

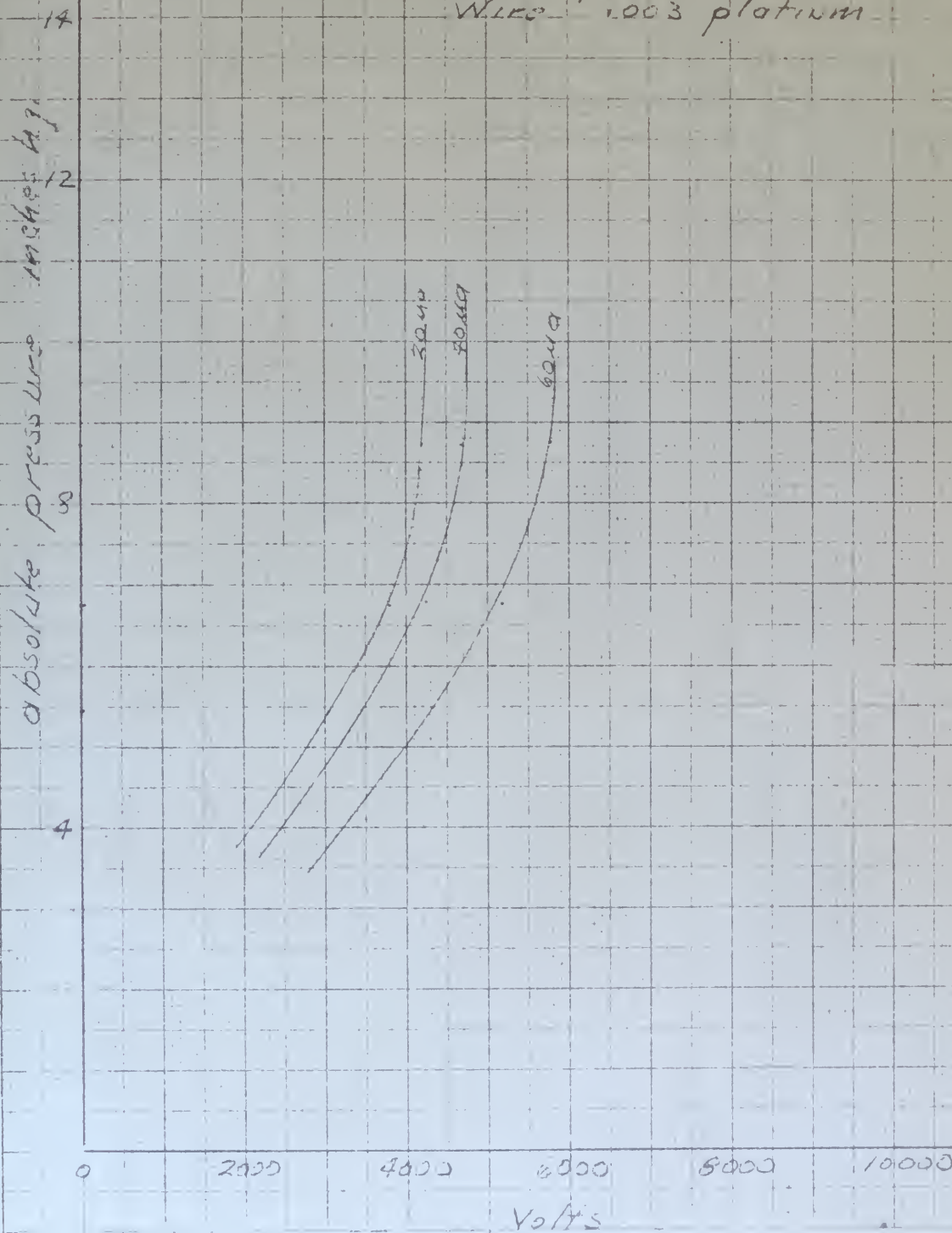


Fig-22-

absolute pressure vs Volts

Mach number 3.1

Spacing .125 inches

Wire .003 platinum

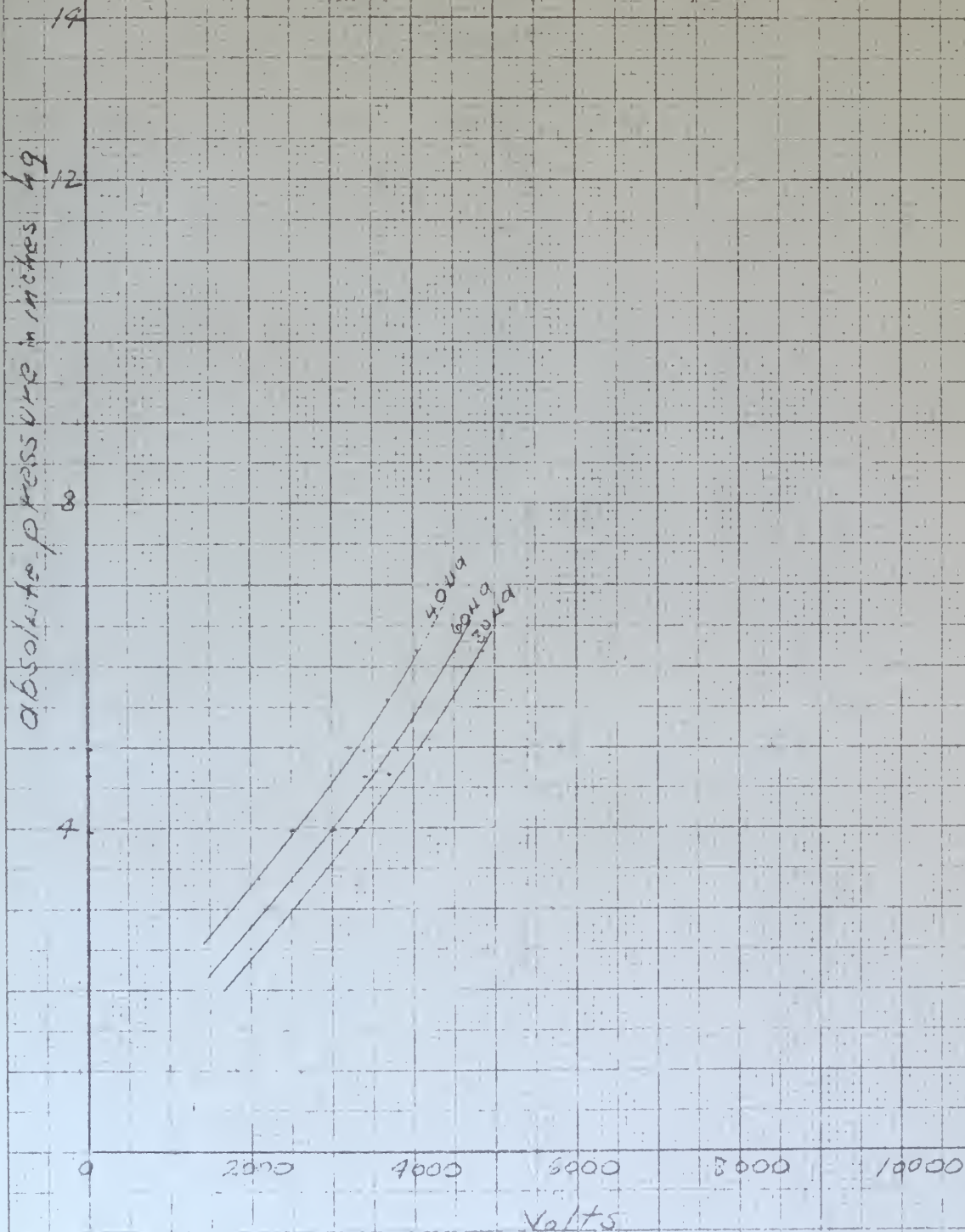


Fig-23-

Microamps vs Volts at const. abs. Pressure
absolute pressure = 5 inches hg.

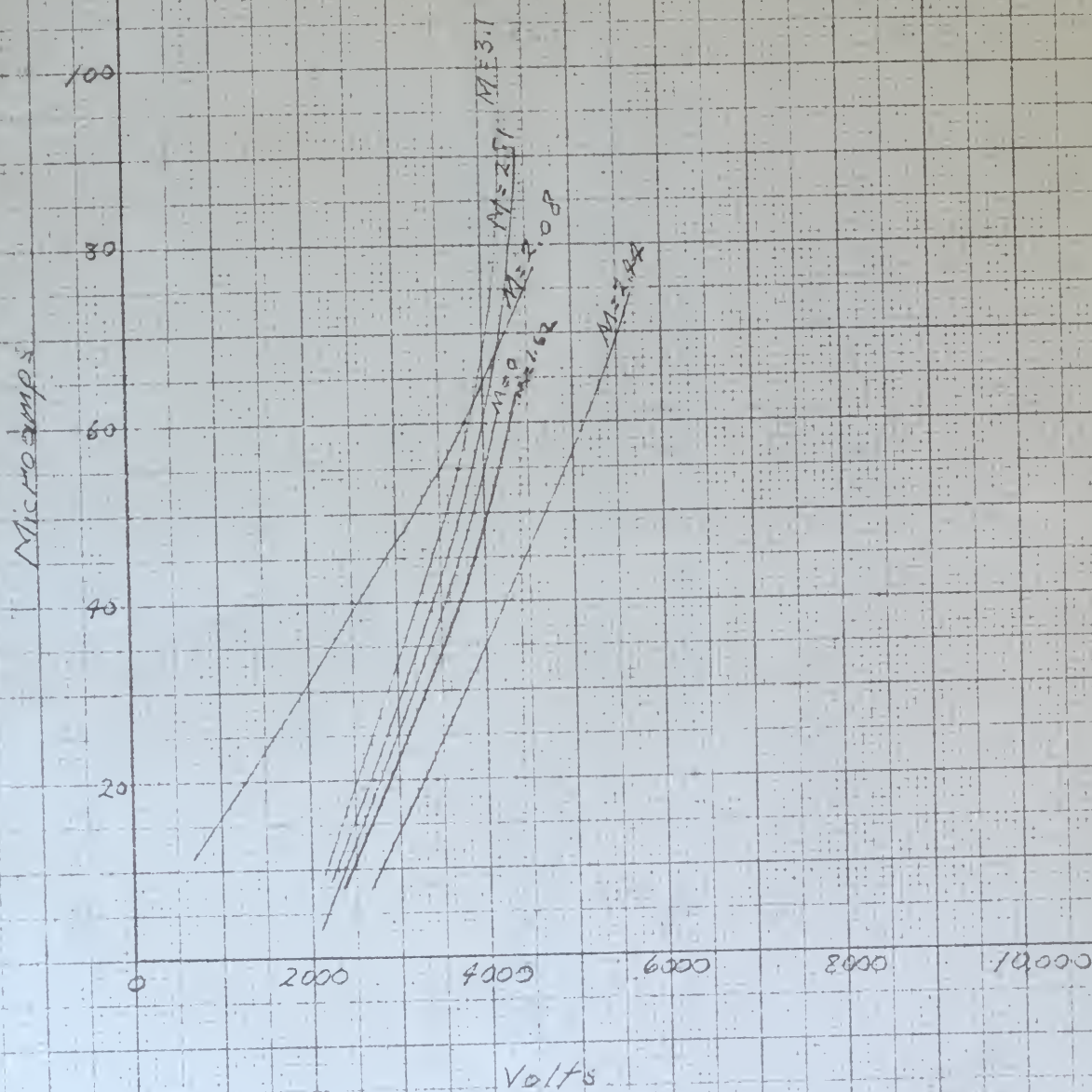
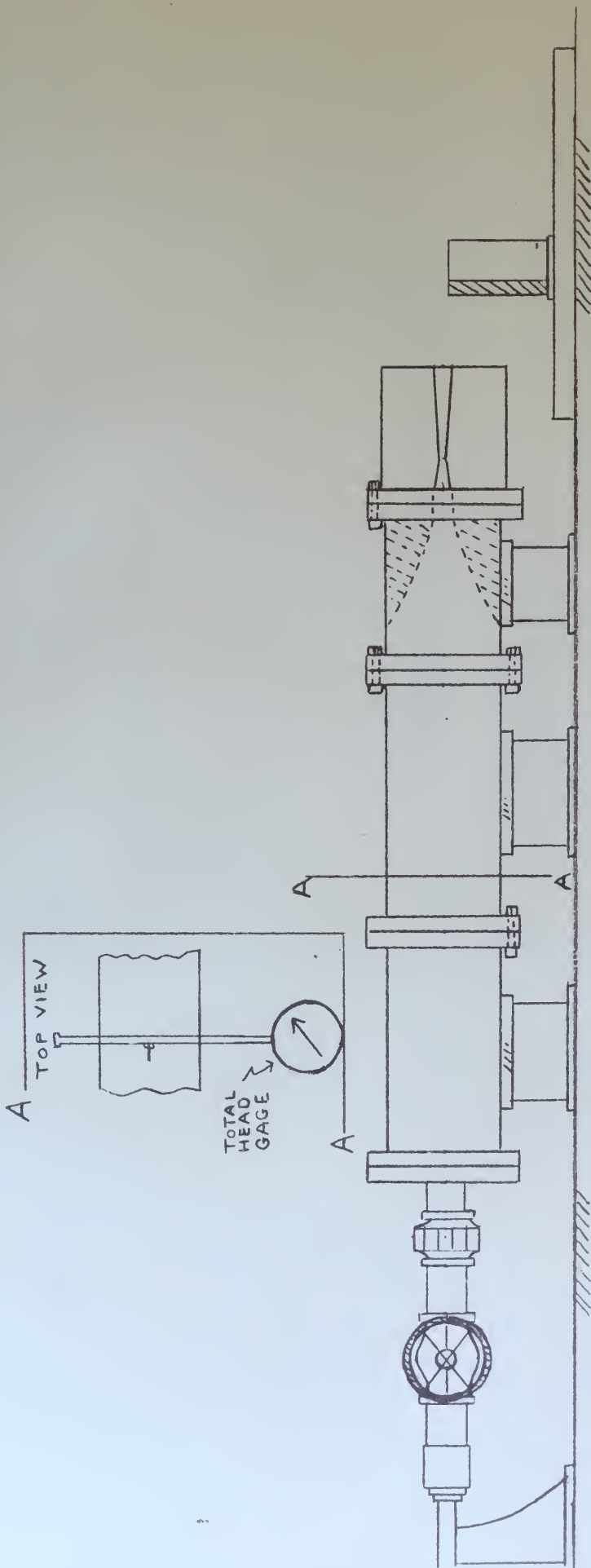


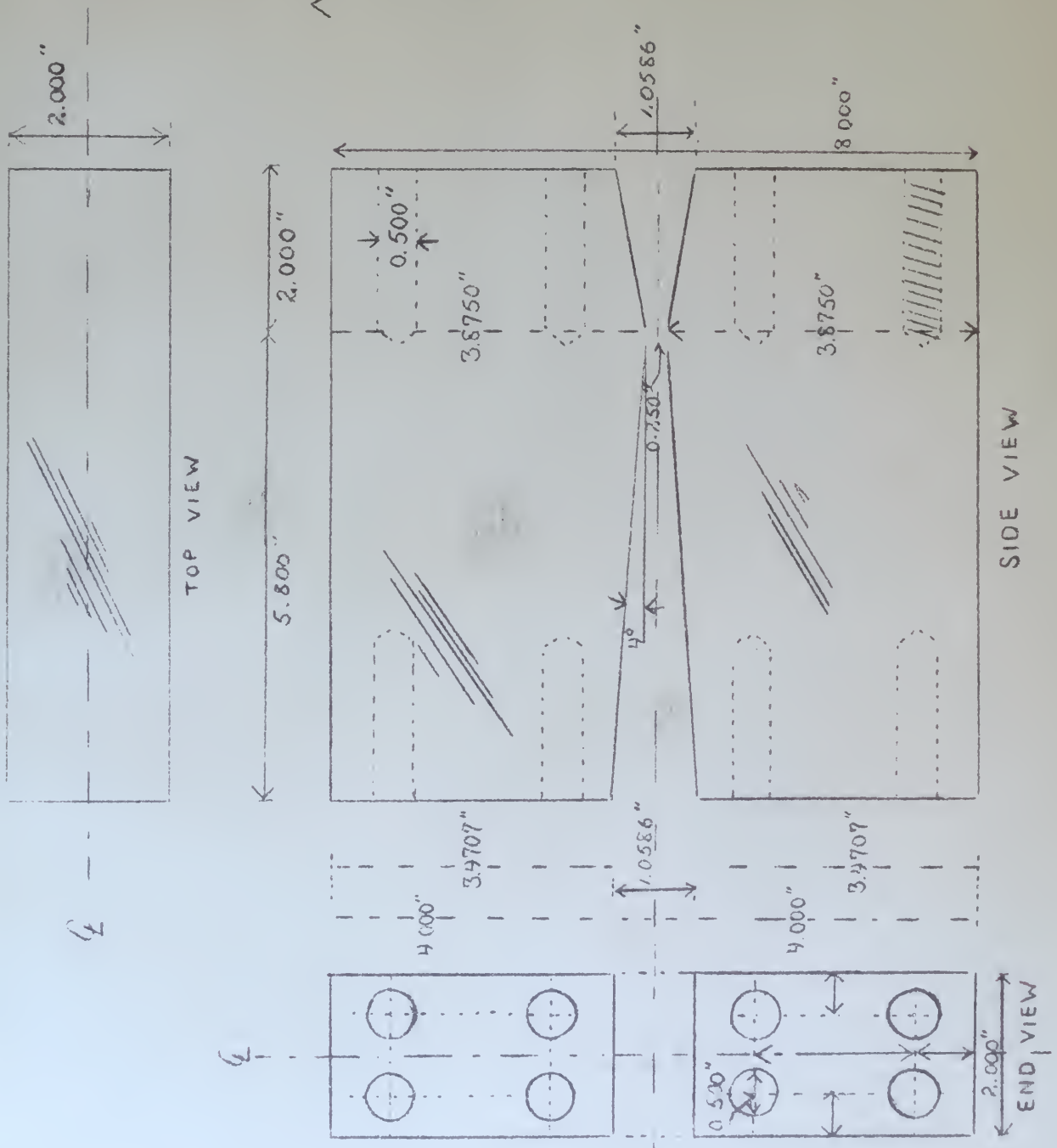
Fig-24-

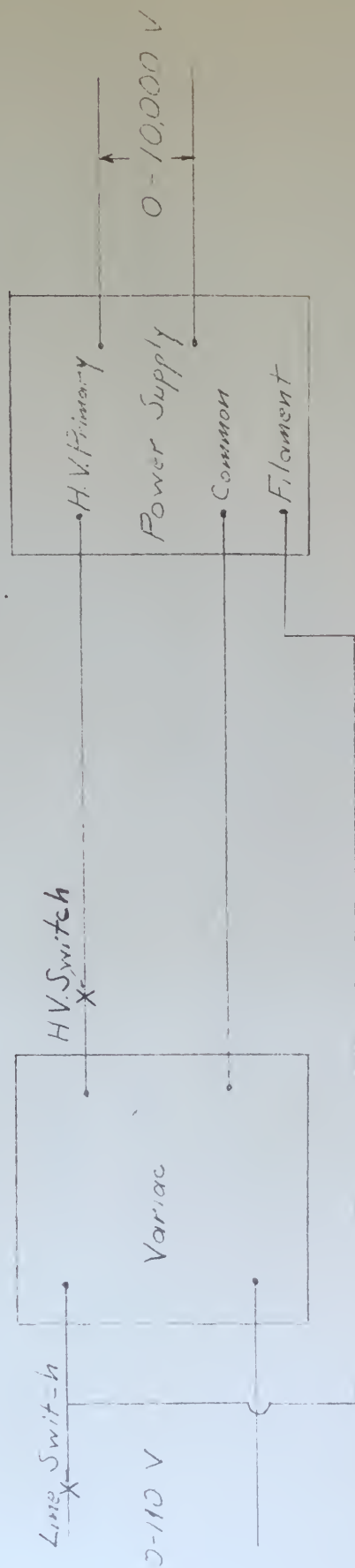


SCALE $\frac{1}{10}'' = 1''$

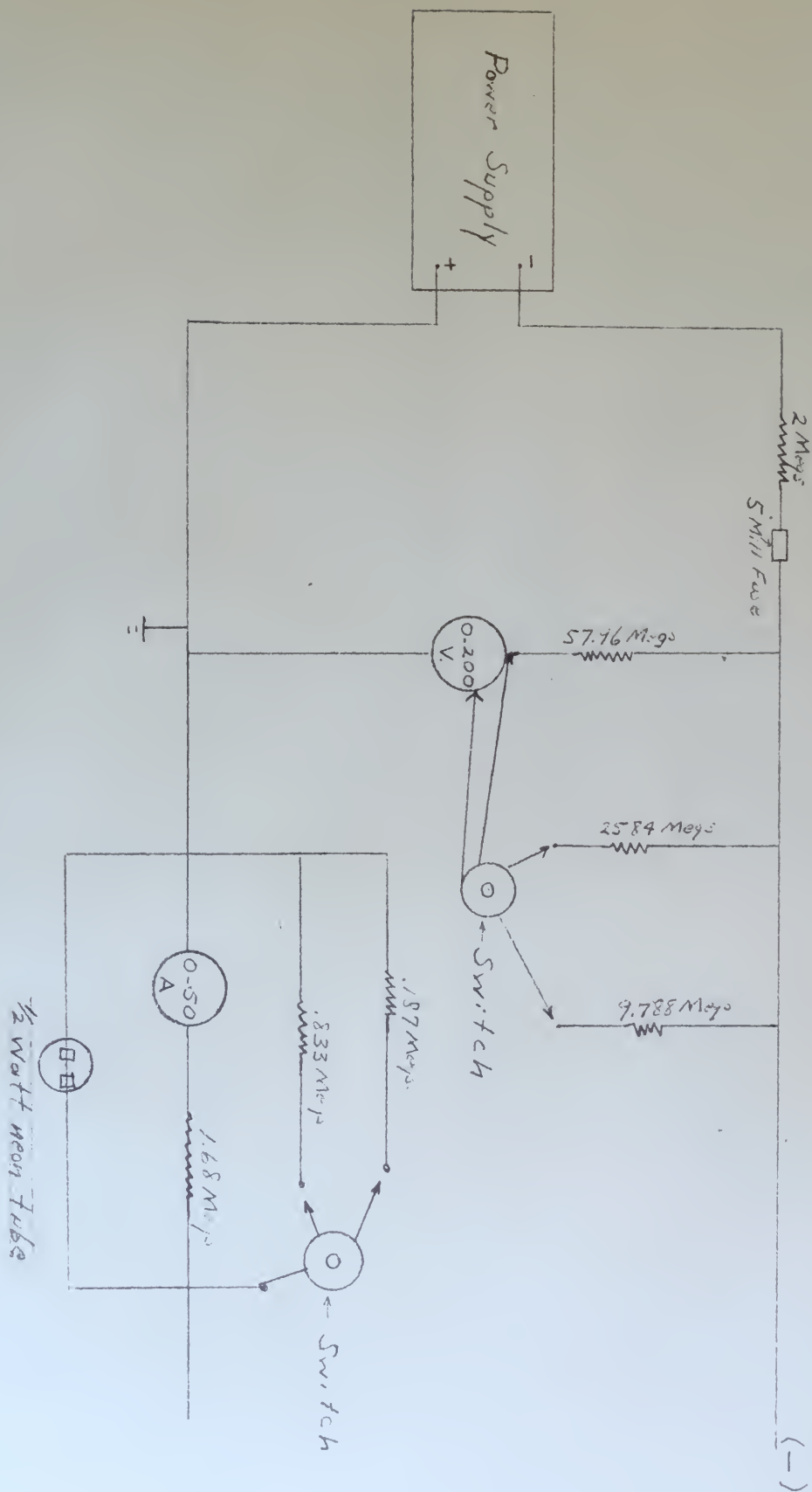
SIDE VIEW
WIND TUNNEL

NOZZLE BLOCK DESIGN

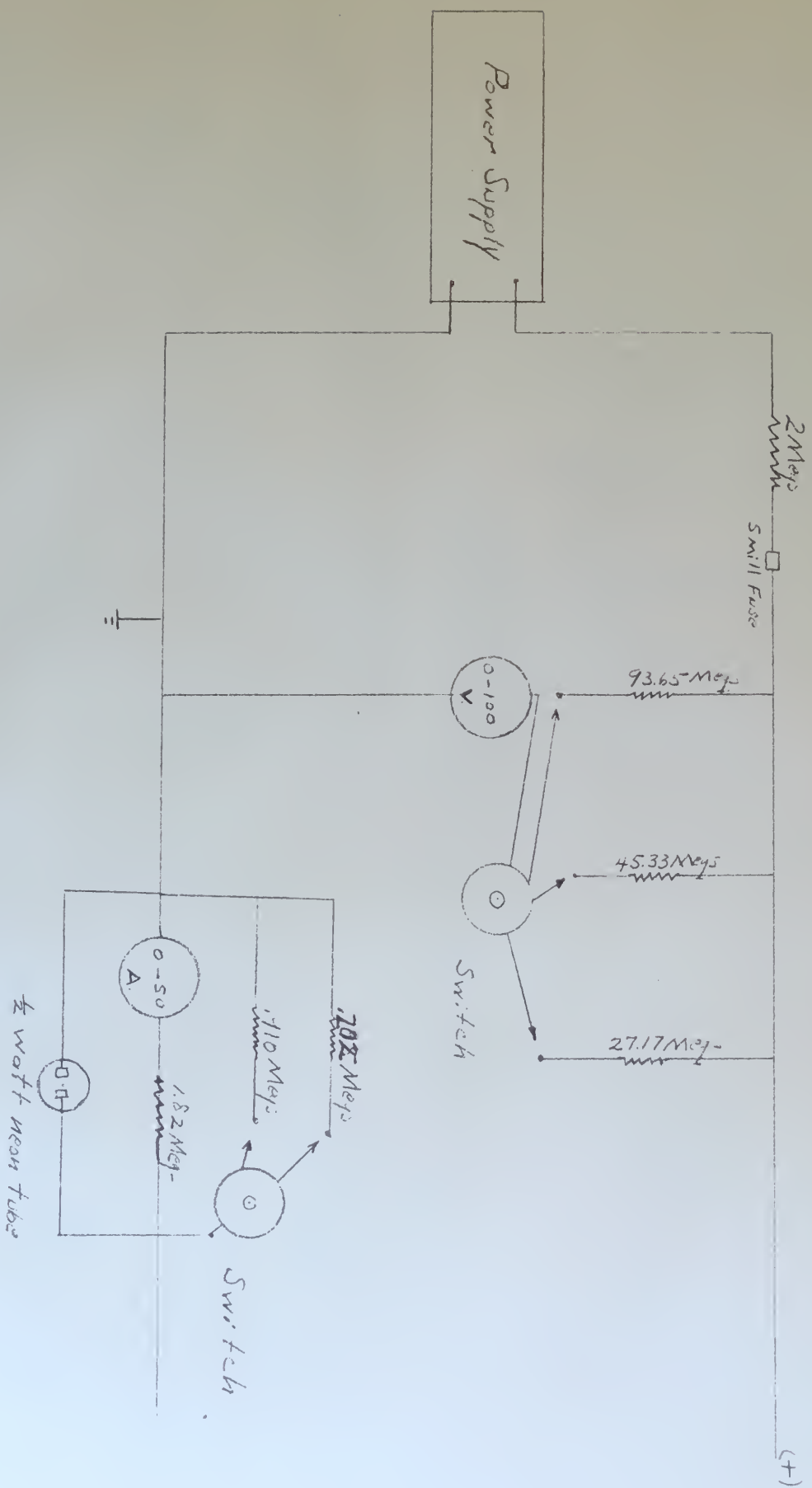




Power Supply

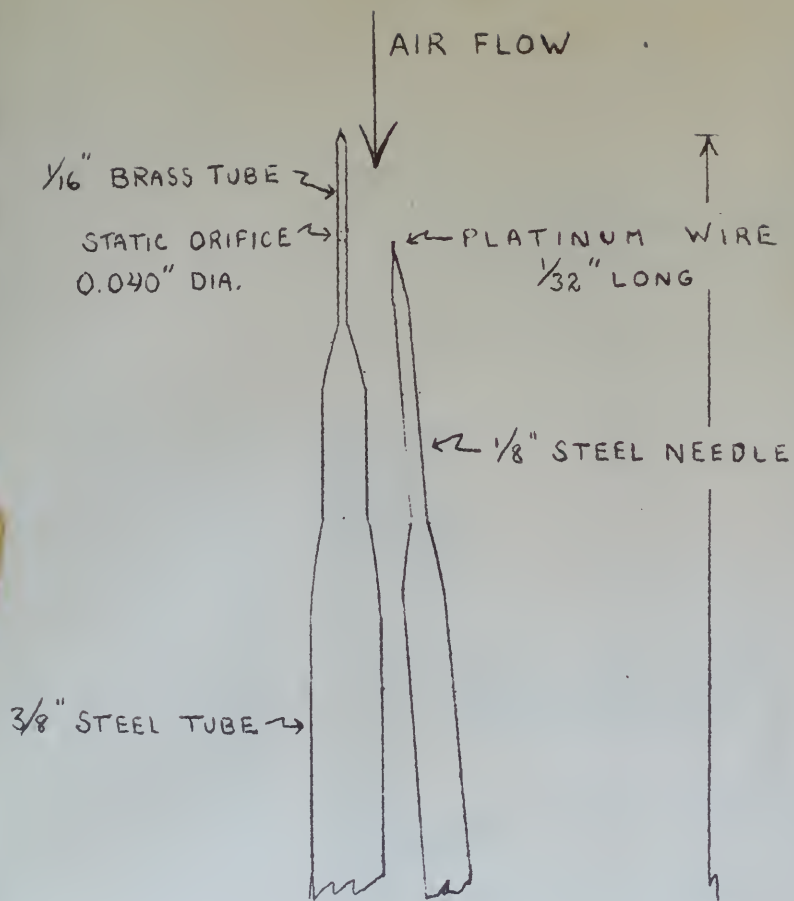


Circuit # 1

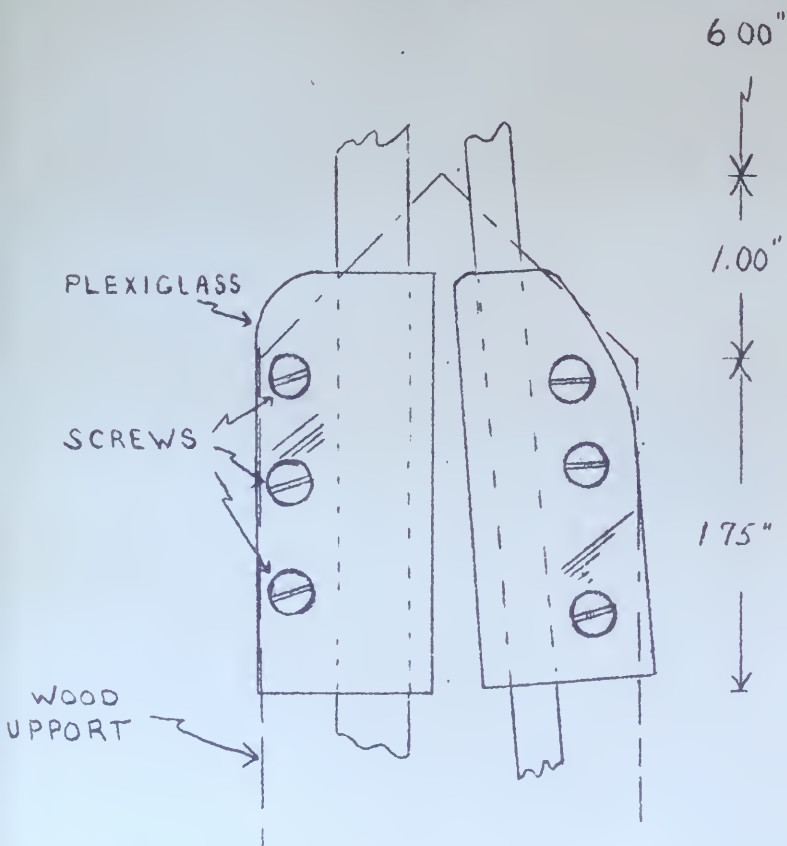


Circuit

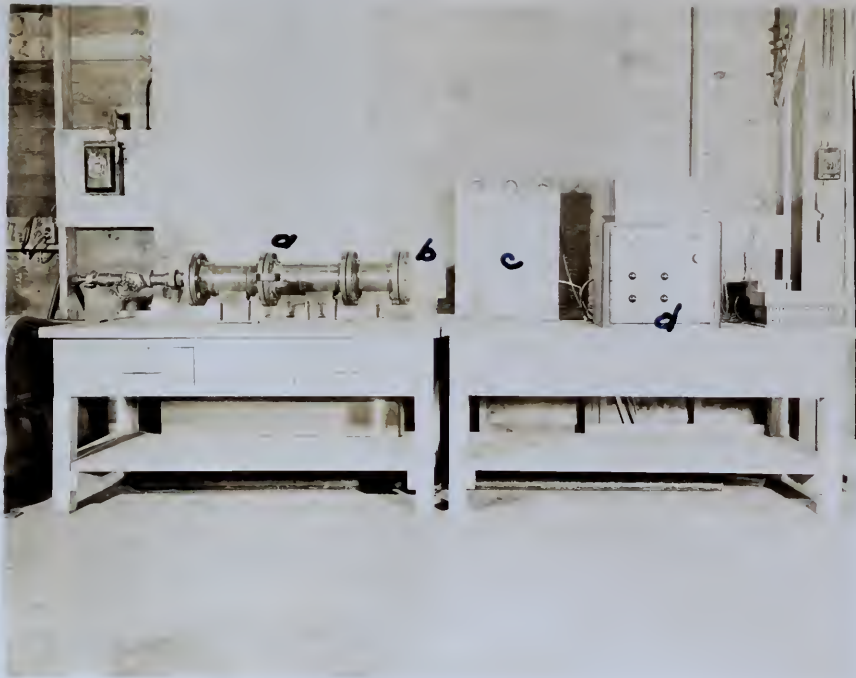
2



ARRANGEMENT of
the PROBES



WIND TUNNEL & ELECTRONIC EQUIPMENT



- a - Stagnation Chamber
- b - Nozzle
- c - Manometer Board
- d - Electronic Equipment

Fig. 31

THE JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION



1 - American Medical Association
 2 - Board of Directors
 3 - American Medical Association
 4 - American Medical Association

NOZZLE BLOCKS, PROBES & VACUUM JAR

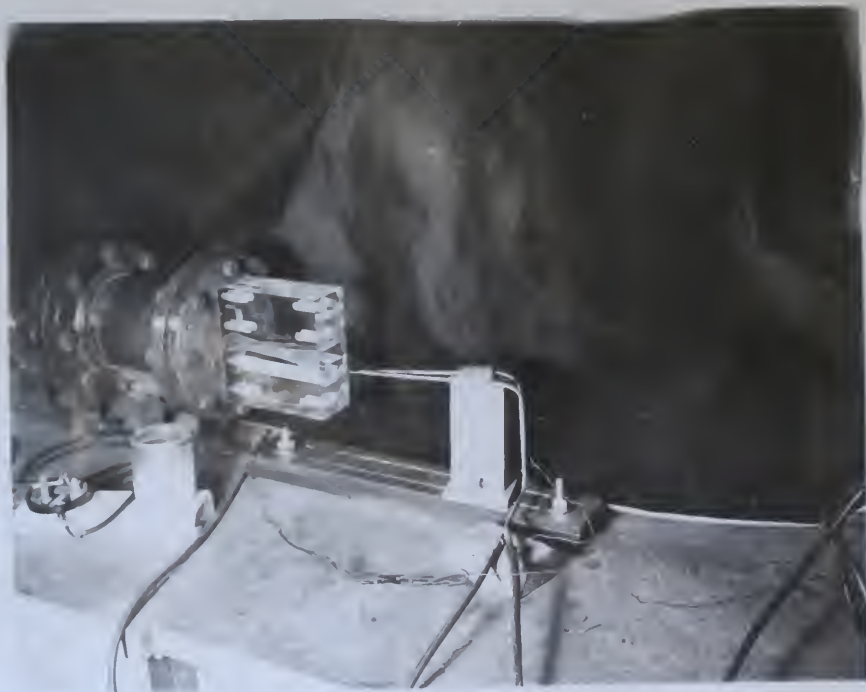
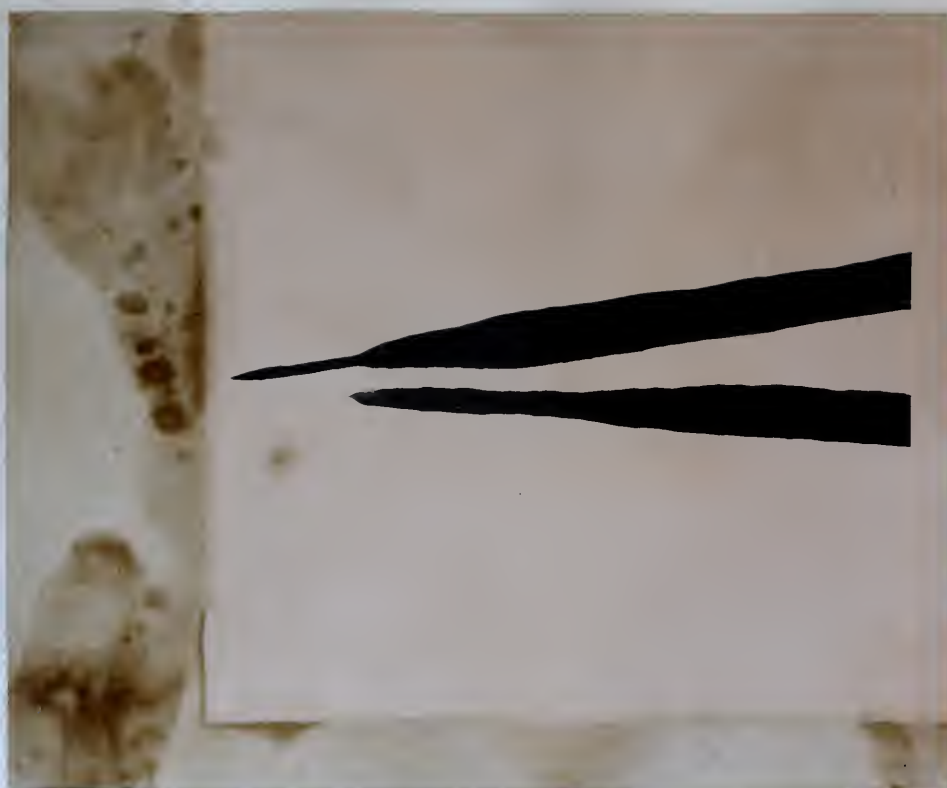


Fig. 32

THE UNIVERSITY OF CHICAGO





Static Probe

Platinum Wire
Probe

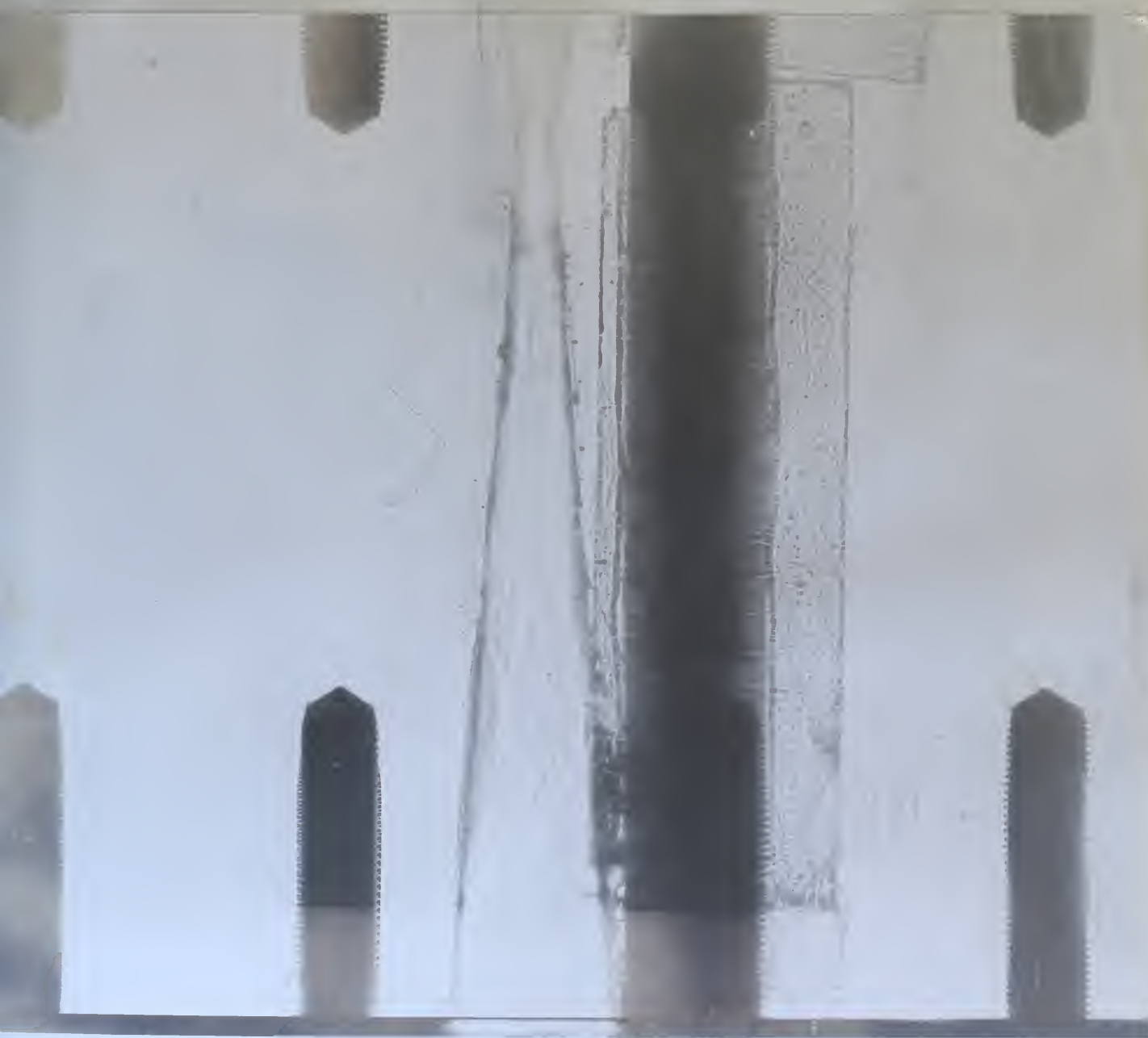
PROBES, SPARK PHOTOGRAPH

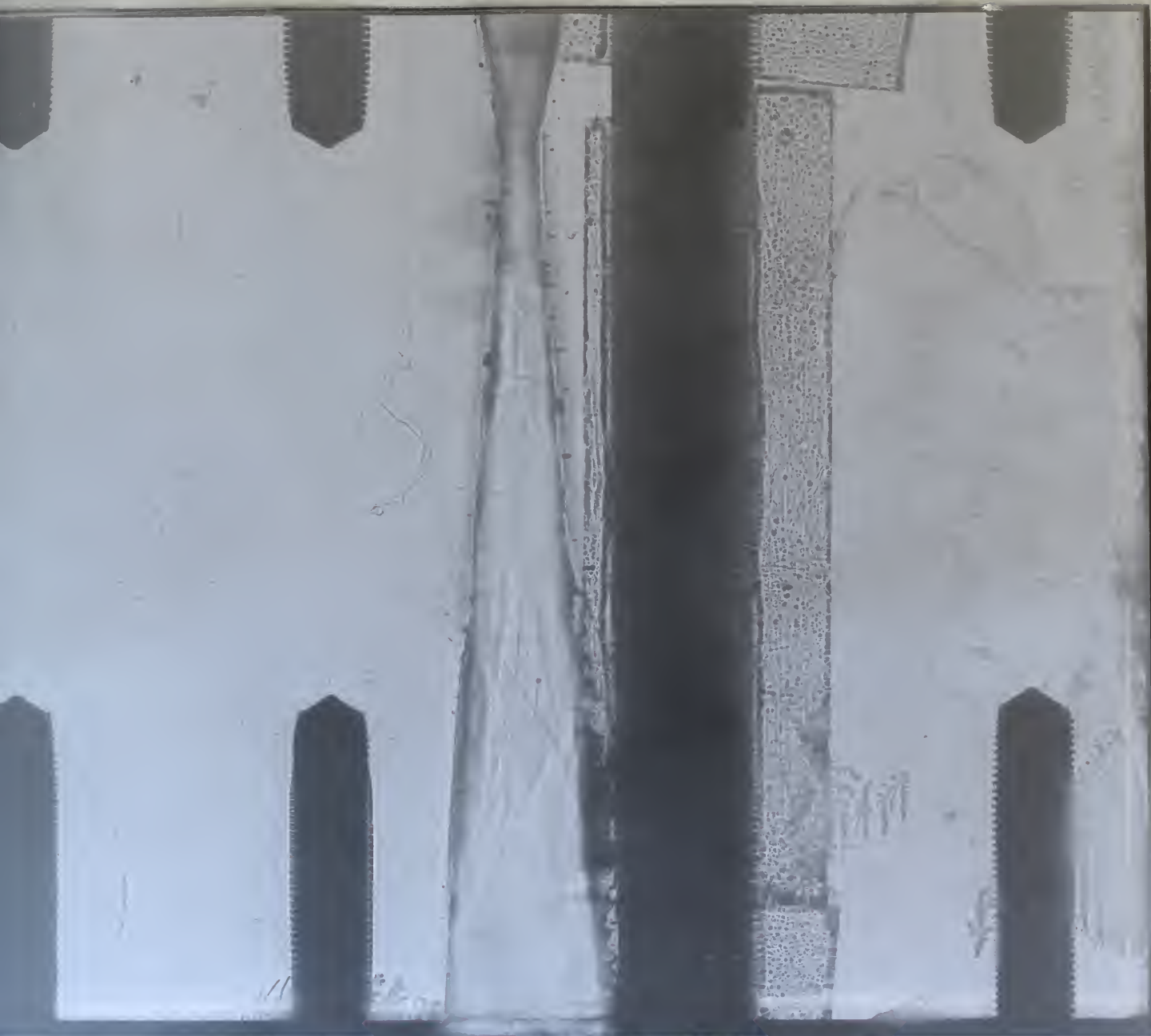
Specimen No. 100

Specimen No. 101



Specimen No. 102





$M = 2.81$; Stagnation Pressure 90#/in.² gage



Prober Inserted
 $M = 2.81$ Stagnation Pressure 90#/in.^2 gage

Fig. 36

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